Six lectures on physical geography

Samuel Haughton

SIX LECTURES

ON

PHYSICAL GEOGRAPHY.

DUBLIN UNIVERSITY PRESS SERIES.

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ON

PHYSICAL GEOGRAPHY.

BY THE

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Pereat, si quis ante nos nostra dixerit!

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PREFACE.

THE substance of the following Lectures on PHYSICAL GEOGRAPHY formed the basis of a Course delivered in the year 1876, for the benefit of the Governess Institution of Ireland.

Owing rather to the excellence of the Institution in whose aid they were given, than to the intrinsic merits of the Lectures, a large number of my audience requested their publication.

In complying with this request, I have made some additions to the Lectures as actually delivered, so as to render them somewhat less imperfect; but they must be regarded rather as a series of sketches of some important features of Physical Geography, than as a formal exposition of this attractive and complex branch of knowledge.

I take this occasion to thank the following friends, who have rendered me valuable literary and scientific assistance during the publication of my Lectures:—Rev. Joseph Carson, D. D.; Alexander Macalister, M.D.; E. Perceval Wright, M.D.; William R. M'Nab, M.D.; and J. Emerson Reynolds, M. D.

TRINITY COLLEGE,
7th February, 1880.

CONTENTS.

LECTURE I.

THE PAST HISTORY AND FUTURE PROSPECTS OF THE GLOBE ON WHICH WE LIVE.

LECTURE II.

CONTINENTS AND OCEANS, VOLCANOES AND MOUNTAINS.

LECTURE III.

THE LAWS OF CLIMATE, ATMOSPHERIC AND OCEANIC CIRCULATION.

LECTURE IV.

THE RIVERS AND LAKES OF EUROPASIA.

LECTURE V.

THE RIVERS AND LAKES OF AFRICA AND SOUTH AMERICA.

LECTURE VI.

ON THE GEOGRAPHICAL DISTRIBUTION OF ANIMALS AND PLANTS.

APPENDIX.

ADDITIONAL NOTES.

LIST OF PLATES.

LECTURE I.*

THE PAST HISTORY AND FUTURE PROSPECTS OF THE GLOBE ON WHICH WE LIVE.

LADIES AND GENTLEMEN,

Forty years ago, a Lecture on the subject I have proposed for our consideration to-day would have been looked upon as the wild dream of a romance writer; yet I hope to show you that such a Lecture may now be attempted, based upon solid facts derived from science and observation, of the consequences flowing from which we as yet see only the beginning.

There have been from the earliest times two classes of speculation on this subject—two distinct poles or forms of thought. In the one case we have a race of people distinctly imagining to themselves a personal creator of themselves and of the universe; a tone of thought leading to an elevation of man above surrounding things, and to a contempt for nature. In the other case, we have a belief in blind formative forces animating matter, involving with it a contempt for man as a miserable unit, as the sport of circumstances, and a corresponding high view of the dignity of nature.

We shall leave the champions of man and nature to

* This Lecture was delivered on the 4th of March, 1876.

fight out their battle on their own ground, and proceed to examine the solid facts relating to the physical structure of the earth and stars, presented to us by observation.

Metaphysicians have speculated as to the possibility of our conceiving the creation of matter out of nothing; but there can be little doubt that such a process is "unthinkable" to beings of our limited faculties. In discussing the past history of our globe, we have, however, no such difficulty to contend with; for our planet can be shown to have been made out of pre-existing materials, the previous history of which can, to a considerable extent, be traced.

The "evolution" of planets from combinations of pre-existing materials by no means involves the denial of a creating and presiding mind; on the contrary, such an evolution as we find in nature—orderly, symmetrical, and regular—constitutes the highest proof we have from natural religion, of the existence and power of God, the Author of nature.

The earliest scientific conception and development of the idea of the evolution of planets is due to the great astronomer and mathematician, Laplace, whose views on this subject are given in note vii., appended to his *Système du Monde:* Paris, 1835. In this note he sketches the outline of his famous *Nebular Hypothesis,* and maintains a common origin for all the parts of the solar system, properly so called,* on the following grounds:—

1. The revolution of the planets in the same direction round the sun.
2. The revolution of the planets round the sun nearly in the same plane.

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* That is, excluding the comets.

3. The revolution of the satellites in the same direction as the planets.
4. The rotation of the sun, planets, and satellites, round their axes in the same direction as the general revolution round the sun.
5. The rotation of sun, planets, and satellites, round their axes nearly in the same plane.
6. The revolution of the planets and satellites in orbits nearly circular.
7. The flattened figures of the planets, especially those endowed with a rapid rotation.
8. The phenomena of Saturn's rings, and of the asteroids lying between Mars and Jupiter.*
9. The exact equality of the times of rotation and revolution of the moon.†
10. The exact and remarkable law connecting together the revolutions of the first three satellites of Jupiter, viz.: *That the mean longitude of the first, plus twice the mean longitude of the third, minus three times the mean longitude of the second, is constantly equal to two right angles.*†

In addition to the foregoing arguments of Laplace, in favour of his Nebular Hypothesis, the following may be mentioned as obvious :—

* In Laplace's time four only of the asteroids had been discovered, viz., Vesta, Juno, Ceres, and Pallas. There are now nearly 200 known and named asteroids. These minor planets revolve between the planets which are rich in satellites and the planets which are poor in satellites, and form a great solar ring. It was at one time supposed that Saturn's rings were solid; but it is now believed that they are composed of star dust—that is, of a number of meteoric stones, severed from each other. In this solar ring, formed by the minor planets, we have a remarkable counterpart of Saturn's rings.

† This result can be explained by admitting the existence of friction, which would be a necessary part of the Nebular Hypothesis.

11. The much greater density of the interior planets (Mercury, Venus, Earth, Mars), as compared with that of the exterior planets (Jupiter, Saturn, Uranus, Neptune).*

12. The inferior density of the Moon, as compared with that of the Earth—

Earth, ...	5·5
Moon, ...	3·1

The Moon has the density of basalt, while the Earth has that of metallic manganese.

13. The much greater number of satellites belonging to the exterior planets, as compared with those of the satellites belonging to the interior planets.†

14. The greater velocity of rotation of the exterior planets, as compared with that of the interior planets.‡

15. The increase of temperature, as we penetrate deeper and deeper into the interior of the earth, showing

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* Taking water as our standard, the densities are :—

Mercury, . . .	6·2	Jupiter, ...	1·3
Venus, ...	5·2	Saturn, ...	0·8
Earth, ...	5·5	Uranus, ...	1·0
Mars, ...	5·2	Neptune, ...	1·3

† The satellites and rings of the several planets are :—

Mercury, .	0 satellite.	Jupiter, .	4 satellites.
Venus, . .	0 ,,	Saturn, .	8 ,, and 2 rings.
Earth, . .	1 ,,	Uranus, .	4–8 ,,
Mars, . .	2 ,,	Neptune, .	1 ,,

‡ The length of the day in the several planets is as follows :—

	h. m.		h. m.
Mercury, . .	24 05	Jupiter. . . .	9 56
Venus, . . .	23 21	Saturn, . . .	10 16
Earth, . . .	23 56	Uranus, . . .	9 30
Mars, . . .	24 37	Neptune, . . .	—

that the earth is a cooling mass, and that it was formerly much hotter.*

Since the time of Laplace we have acquired additional knowledge respecting the composition of the bodies in space outside the earth, which enables us to add on two more arguments in favour of the Nebular Hypothesis, which are of very great weight and importance.

16. The chemical composition of meteoric stones.
17. The chemical composition of the sun and stars.

Our accurate knowledge of the chemical composition of meteoric stones, which enter the earth's atmosphere from the interplanetary spaces, and fall upon its surface, dates from a period subsequent to Laplace.

We are now able to count in our catalogues within the last fifty years hundreds of meteoric stones, and by comparing these with the dust on our mountains we are enabled to say that there is a quantity of fine dust—meteoric dust—constantly falling. But in this large collection of meteoric stones there is not a single element that is not terrestrial, although the elements exist in crystallised forms sometimes different from those found on the earth.

There are sixty-five chemical elements recognised at present by chemists, as constituting the primary basis of all substances of terrestrial origin, and of these twenty-seven are said to have been found in the meteoric stones, which

* The temperature of the ground varies with the season of the year down to a depth at which the temperature begins to be constant. This depth increases with the latitude; being 1 foot at the equator, and 60 feet in our latitude. At depths below the invariable layer the temperature has been found, in different localities, to increase at the rate of 1° F. for every 40-80 ft.; the mean 1° for 60 ft. being probably the true mean rate of increase.

come to us as visitants from the interplanetary spaces ;* and (as I have said before) not a single element that is non-terrestrial, or foreign to our globe.

By means of the spectroscope, it has been ascertained that the terrestrial elements found in meteoric stones may be found also in the sun, in the comets, and in the distant stars and nebulæ residing in space far beyond the humble limits of our solar system.† Of the *sixty-five* terrestrial elements known to chemists, twenty-one have been detected already in the sun and stars.

These facts render it probable that the entire universe

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* The meteoric elements are the following :—

METALLIC.

Aluminium.	Cobalt.	Nickel.	*Antimony.
Calcium.	Copper.	Titanium.	*Arsenic.
Chromium.	Magnesium.	Tin.	*Lead.
Iron.	Manganese.		*Yttrium.
Potassium.	Sodium.		*Zirconium.
			*Lithium.
			Vanadium.

NON-METALLIC.

Silicon.	Phosphorus.	*Chlorine.
Carbon.	Sulphur.	Hydrogen.
Oxygen.		

The seven elements marked thus (*) have either not been identified with certainty in meteorites, or were, possibly, derived from the soil in which the mass fell.

† The following Table, for which I am indebted to Mr. Burton, of the Dunsink Observatory, shows the present state of our knowledge on this subject:—

Substances shown by the Spectroscope to exist beyond the Limits of the Earth's Atmosphere.

METALLIC.

Sodium,	(*a*) (*b*).	Iron,	(*a*) (*b*).	Bismuth,	(*c*).
Potassium,	(*a*).	Cobalt,	(*b*).	Tellurium,	(*c*).

is composed of some 100 elements, which in no respect resemble the blind atoms of Epicurus, but present all the appearance, from the outset, of well-considered, carefully-wrought, manufactured articles, fresh from the hand of an Omnipotent Contriver, in whose works

"*Nihil est temerarium, nihil varium, nihil fortuitum.*"

The earth and moon must be regarded rather as a binary system than as that of a planet and its satellites. The earth at the time it was thrown off from the sun had a revolution on its axis in precisely the same time as it now takes to revolve round the sun; that is, there was one day and night, equal in duration to 365 days 6 hours. The change that has ensued was in accordance with a law that regulates the rotation of bodies. If you could suddenly reduce a body rotating on its axis into a smaller bulk, it

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Calcium, (*a*) (*b*).	Nickel, (*a*) (*b*).	Antimony, (*c*).
Barium, (*a*) (*b*).	Chromium, (*b*).	Mercury, (*c*).
Aluminium, (*b*).	Manganese, (*b*).	
Magnesium, (*a*) (*b*).	Titanium, (*b*).	
	Copper, (*a*) (*b*).	

NON-METALLIC.

Hydrogen, (*a*) (*b*).	Carbon, (*c*).	Nitrogen, (*c*).
	Oxygen (*Draper*, 1876).	

AUTHORITIES.

(*a*). *Kirchhoff und Hofmann.*—"Researches on the Solar Spectrum and the Spectra of the Chemical Elements." Macmillan, 1863.

(*b*). *Angström.*—"Recherches sur le Spectre Normal du Soleil." 1869. Upsal: W. Schultz. Berlin: Ferd. Dümmler.

(*c*). *Huggins and Miller.*—"Proc. Roy. Soc.," xii., 444. "Phil. Trans.," 1864, pp. 413 and 437. Monthly Notices, Royal Astr. Society, xxvi., p. 215.

must revolve more quickly.* Therefore the revolving mass constituting the earth and moon, as it gradually became condensed, revolved faster and faster upon its axis, until at last the length of the day became what it is now. But on this theory it might be asked, why does the moon, which is composed of the same materials, rotate on its axis at a different velocity from the earth? The answer to this has been anticipated by Laplace, and is contained in Argument No. 9, given above, which involves the idea of tidal, or other friction, subsequently indicated by Professor Frankland. The idea is suggested by the action of the sun and moon on the tides, and the conclusion come to is, that the action of the moon upon the water must tend to stop the rotation of the earth. This being so, after the earth and moon separated from the sun contraction continued, the rotation increased, and the moon, at one time in her history, like the earth, was spinning much faster than when she separated from the sun. But at last there must have come a time when the rate of increase of motion arising from contraction would be insufficient to counteract the influence of the action of the earth upon the loose materials of the moon, and its tendency to stop the rotation. Just before this the moon's rotation would have been at its maximum, and (as it will be with the earth) the rotation became slower and slower. The prospect now lies before us on this globe—the cheerless prospect—of having our

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* The law here referred to is the following:—

$$\omega = \frac{G}{I},$$

where ω = velocity of rotation.
G = primitive couple producing rotation.
I = moment of inertia.

As the moment of inertia *diminishes* by the contraction of the planet from loss of heat, the angular velocity *proportionately increases*.

day and night become longer and longer, in consequence of the never-ceasing friction of the tidal residual current; until at length the inhabitants even of the equator shall have a six months' day and a six months' night, with the prospect in the far future of a period of axial rotation (like the moon) equal to that of the revolution of the earth round the sun. When the length of the day shall have become equal to the length of the year, tidal friction will cease, and one half of the earth will possess eternal sunshine, while the other half is clothed in eternal night. It would be difficult to conceive which of the two portions of the earth would suffer most; but we may console ourselves with the reflection, that the time is so remote that it concerns us little—"*après moi le déluge.*" Thus the moon holds up to us the mirror that shows our future history.

We know, from a study of the facts revealed by mining operations, that the outer surface of the earth is fissured deeply with cracks, or faults, penetrating downwards to unknown depths. Whatever air or water finds its way into these cracks is lost to us; and it is believed that already one-third of the whole mass of the ocean on our globe has been absorbed in this way by the minerals in the earth. The earth is, therefore, gradually losing its water and its atmosphere; and if we could live long enough, we should see the earth without water, without an atmosphere—a condition of things in which it is very certain that neither animal nor vegetable life would be possible.

A few years ago an astronomer would have laughed at you, if you questioned the accuracy of his great clock, the sidereal day depending on the constancy of the period of the earth's rotation; but recently it has been asserted, on high authority, that we must admit that the length of the sidereal day is slowly increasing.* If this be so, the earth has already passed the critical period of her history. Our

* A short account of the manner in which this increase in the length of the day has been discovered will serve to show the reader some of the methods used in astronomical calculations.

The mean motion of the moon round the earth was formerly assumed to be constant, until Halley showed that it has been gradually increasing by a small amount during the last few thousand years. Halley made this discovery by the study of ancient solar eclipses, which were found always to occur to the *eastward* of their calculated places:—this indicates a slower mean motion of the moon in former times, as may be thus shown. A spectator in the northern hemisphere looking at a solar eclipse will face the south, having the west on his right hand, and the east on his left hand; and he will see the moon cross the sun's disc from right to left. When we calculate backwards to an old eclipse (attributing to the moon her present mean motion), we are, in fact, *unwinding*, from left to right, the path she has described since the eclipse happened, and by this unwinding process we find that we always place the moon to the *right* (*west*) of the place where she was actually when the eclipse occurred. Thus, all the ancient eclipses being observed at places to the *eastward* (*left*) of their calculated places of observation, we learn that the moon's mean motion was formerly slower than it now is. The coefficient of the moon's mean motion, found by Halley, from ancient eclipses, was

$$10{\cdot}2 \times n^2,$$

where n is the number of centuries.

The acceleration of the moon's mean motion was first explained by Laplace, who showed that the mean central disturbing force of the sun, by which the moon's gravity towards the earth is diminished, depends not only on the sun's mean distance, but on the eccentricity of the earth's orbit. This eccentricity has been diminishing for many ages, while the mean distance remains unaltered. In consequence of this, the sun's mean disturbing force is diminishing, and, consequently, the attraction of the moon towards the earth has been increasing, and with it, of course, the mean motion of the moon has been also increasing. The calculations of Laplace, confirmed and extended by Damoiseau and Plana, gave a coefficient for the moon's mean motion agreeing with that found from observation by Halley.

This satisfactory agreement between theory and observation remained unchanged until 1853, when Adams announced* that he had found a deficiency

* "Proceedings Royal Society," vol. vi., p. 321.

days will now slowly lengthen, and the time may be looked forward to when, the atmosphere and the water

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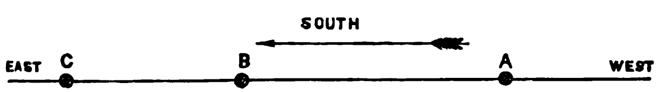
in Laplace's calculation, arising from the fact that Laplace had considered the radial disturbing force only, and had neglected the tangential disturbing force.

When the fuller computation is made, it is found that the coefficient of Halley's expression is reduced from 10·2 to 6·11, leaving 4·09 not accounted for.

Adams' calculations were verified by Delaunay, who found them quite correct, and who had the merit of suggesting the explanation of the 4·09, which form a *residual phenomenon*. According to Delaunay, this uncompensated portion of Halley's coefficient is to be explained by the retardation of the earth's angular velocity, and consequent increase in the length of the day, caused by the residual tidal current setting constantly from east to west. This residual current, although excessively small, is a *vera causa* always acting, and must, in due course of time, produce a sensible effect in lengthening the day. It is easy to show that the effect of the lengthening of the day upon ancient solar eclipses acts in the same direction as the acceleration of the moon's mean motion—viz., it throws the place of observation to the eastward (left) of the calculated place; for the earth moves from right to left, in the same direction as the moon, and as its rotation in that direction, from the period of the eclipse, has been *greater* than that assumed in our calculation from the *present* rotation of the earth, it follows that, when we *unwind* from left to right the place of observation, we shall bring it, in our calculation, to the left (eastward) of the actual position of the eclipse. According to this view, therefore, the displacement eastwards of the places of observation of ancient eclipses, when compared with the calculated places of observation, is the sum of two displacements—one caused by not allowing for the *acceleration of the moon*, and the other caused by not allowing for the *retardation of the earth*.

Thus, if B represent the true position of the eclipse in space, its calculated place will be A, to the west of B, the interval AB being due to the



neglect of the acceleration of the moon's mean motion (with coefficient = 6·11) in the calculation; and the place where the eclipse was observed, which was at B at that time, will be placed by our calculation at C, to the having been absorbed, the earth will be reduced to the condition in which the moon now is—a sort of dry burnt-

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eastward, in consequence of the neglect of the retardation of the earth's rotation in the calculation.

Let us illustrate the case by one of the most famous solar eclipses on record—that of Agathocles, on the 15th August, 310 B.C. The accompanying outline map represents the course taken by the Expedition of Agathocles from Syracuse to Carthage.*

This eclipse is recorded by Diodorus Siculus, and has been always considered one of the most important in support of Halley's coefficient, 10·2 seconds.

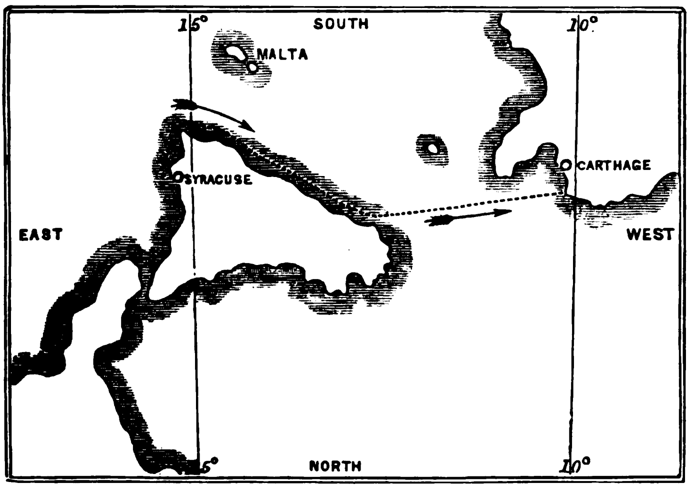
It has recently, however, been called in question by a high authority; for at the meeting of the American Association for the Advancement of Science (1877), "Professor Simon Newcomb presented a communication on "the secular acceleration of the moon, and its increasing deviation from uniformity through many years. He reviewed the existing theory on the "subject; the calculation of Laplace according with Halley's estimate of the "acceleration as about 10½ seconds of time, to be multiplied by the square "of the centuries for a given period; also the Adams theory, which reduces "the explanation of Laplace to 6 seconds, leaving more than 4 seconds to be "otherwise accounted for. In ascribing the surplus acceleration to diminished rotation of the earth, we are dealing with a subject where the evidence should be carefully weighed. Much dependence seemed to be placed

* The places passed in order, by the Expedition of Agathocles, along the Sicilian coast, are described in the fine lines of Virgil:—

Sicanio prætenta sinu jacet insula contra
Plemmyrium undosum: nomen dixere priores
Ortygiam. Alpheum fama est huc Elidis amnem
Occultas egisse vias subter mare: qui nunc
Ore, Arethusa, tuo Siculis confunditur undis.
Jussi numina magna loci veneramur: et inde
Exsupero præpingue solum stagnantis Helori.
Hinc altas cautes projectaque saxa Pachyni
Radimus, et fatis nunquam concessa moveri
Adparet Camarina procul campique Geloi,
Inmanisque Gela fluvii cognomine dicta,
Arduus inde Acragas ostentat maxima longe
Mœnia magnanimûm quondam generator equorum,
Teque datis linquo ventis, palmosa Selinus,
Et vada dura lego saxis Lilybeia cæcis.
Hinc Drepani me portus et inlætabilis ora
Adcipit.—*Æn.*, lib. III., 692–708.

out cinder. A French astronomer has gone a little further, and ventured to predict what will become of the moon—

"on the record of ancient eclipses. Professor Newcomb considered these "eclipses separately. *The most promising of the Greek solar eclipses was that "of Agathocles, tyrant of Syracuse, occurring at the commencement of his "voyage to attack Carthage. But we do not know on which side of Sicily he "sailed: according to whether he was on one or the other side of the coast, "the difference of time for that eclipse may be calculated as justifying the* 10 "*seconds or the* 6 *seconds acceleration of the moon.* The eclipse known as



"that of Thales has a record still more open to criticism, because it came "to its historian by hearsay, and probably through two or three generations after the lapse of a hundred years. It seems curious that if Thales "predicted the year (by an estimate of lunar periods) he did not also predict "the day. Each of the ancient solar eclipses yielded similar elements of "doubt, on careful examination. From the records of lunar eclipses, if all "uncertain features be weeded out, the old estimate of acceleration will be "reduced one-half. The Arabian records of lunar eclipses were published at "Leyden in the early part of this century. The work is very rare. Altitudes of sun and moon are constantly given in it. Calculations from these "eclipses give the smaller estimate of acceleration. From all the data he "has been able to study, Professor Newcomb concludes that the whole namely, that the water that has been absorbed by her will combine with the chemical elements of her interior, with

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"amount of acceleration is about 8·4 seconds. He hopes to make further "estimates from modern records, having had the good fortune to pick up in "Paris carefully compiled data of occultations going back to 1680."

Let us compare this statement of Professor Newcomb with the original account of Diodorus Siculus. Agathocles was blockaded in Syracuse by the Carthaginian fleet, and the town was in danger of starvation; under these circumstances he formed and carried out the daring project of breaking the blockade, and undertaking an expedition by sea against Carthage itself, which he successfully accomplished. Diodorus says: "But Agathocles, "thus overtaken and surrounded, hit upon an unexpected chance of escape "when night came on; and on the following day there came to pass so great "an eclipse of the sun that night appeared universally, the stars being seen "in every direction; wherefore the people of Agathocles, believing that the "Divinity foreshadowed some evil to happen them, were in still greater "anxiety of mind than before. When they had voyaged for six days and as "many nights, at the dawn of day the fleet of the Carthaginians ap-"peared unexpectedly, not far off. . . . . But when Africa came in sight, "an incredible exhortation to the rowers and rivalry took place. The ships "of the barbarians indeed went faster, because for a length of time they had "been accustomed to the handling of the oars; but the ships of the Greeks "preceded them by a small interval; and, having finished their voyage as "quickly as possible, they immediately sprang upon the strand like "wrestlers; and, indeed, the leading ships of the Carthaginians attacked the "aftermost ships of Agathocles, having come within range of missiles."—Diod. Sic., lib. xx., ch. 5, 6.

Ὁ δ' Ἀγαθοκλῆς περικατάληπτος ἤδη γενόμενος, ἐπιλαβούσης τῆς νυκτὸς, ἀνελπίστου σωτηρίας ἔτυχε. τῇ δ' ὑστεραίᾳ τηλικαύτην ἔκλειψιν ἡλίου συνέβη γενέσθαι, ὥστε ὁλοχερῶς φανῆναι νύκτα, θεωρωμένων τῶν ἀστέρων πανταχοῦ. . . . Ἓξ δ' ἡμέρας καὶ τὰς ἴσας νύκτας αὐτῶν πλευσάντων, ἀποφαινούσης τῆς ἕω, παραδόξως ὁ στόλος τῶν Καρχηδονίων οὐκ ἄποθεν ὢν ἑωράθη.

From this narrative it can be clearly shown that Professor Newcomb is mistaken, when he says that "*we do not know on which side of Sicily he sailed.*" It is quite certain that the eclipse occurred before the expedition had weathered the promontory of Pachynus, or had made any sensible westing in their voyage.

The total distance, on a coasting voyage from Syracuse to Carthage, is the ultimate effect of causing contraction, the effect of which will be to cause the moon ultimately to fall asunder

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350 English miles, and the distance from Syracuse to Cape Pachynus is 40 miles. Now, the whole time of the voyage was six days and as many nights, together with a portion of a night at Syracuse and a portion of a day near Carthage (the Stone Quarries). Allowing six hours each to these, we have

	Hours.
Part of night of outset at Syracuse, ...	6
Six days and as many nights, ...	144
Part of day near Carthage before landing at the "Stone Quarries,"	6
	156

This is the minimum time allowable from the narrative, and any longer time allowed will strengthen my argument. The rate of rowing during the voyage was, therefore,

$$\frac{350}{156} = 2\cdot25 \text{ miles per hour.}$$

At this rate of rowing, it would require 17h. 48m. to reach Cape Pachynus, a distance of 40 miles; so that if the expedition sailed at midnight, it would have been off Pachynus, to the eastward, at 5 p.m., which is the time assigned by Petavius for the middle of the eclipse (Syracusan time). It is, therefore, perfectly clear that if the expedition had got so far to the westward as to allow of the coefficient 6·11, the eclipse must be thrown into the wrong day, which is inadmissible.

If Delaunay is to be trusted, the expedition must have gone out of the Mediterranean into the Atlantic before the coefficient 6·11 could be verified. He says:—"Nous avons dit que la durée du jour augmentait d'une seconde "dans l'espace de 100,000 ans. Mais cela se produit progressivement, de "telle manière que ces augmentations successives des jours s'ajoutent, et au "bout d'un grand nombre de jours font un total appréciable. Si on remonte "à une époque de 2400 ans, époque à peu près à laquelle on rapporte les "éclipses historiques dont on a parlé, on voit que l'observation de l'une de ces "éclipses a dû être faite $1^{h}\frac{3}{4}$ plus tôt que si le ralentissement du mouvement "de rotation de la terre n'avait pas existé.

"La variation relative aux anciennes éclipses va donc jusqu'à $1^{h}\frac{3}{4}$. Ainsi "une éclipse a été observée à un certain moment $1^{h}\frac{3}{4}$ plus tôt qu'elle ne "l'aurait été sans le ralentissement.

"Prenons les trois éclipses principales rapportées par l'histoire. Celle de like an over-boiled potato, thus reducing her to the original condition of meteoric stones from which she came.

In conclusion, I have to express my belief, that there is nothing to lessen, but rather much to increase, our admiration of the wisdom of the Creator, in our contemplation of such a system of the universe as that I have attempted to describe. Let us never think for a moment of banishing that Creator from our thoughts in our contemplation of Nature. Our globe has a life history like ourselves—an infancy, a youth, an old age, a death; and we may now assert, with a degree of confidence, that the countless worlds that surround us have also had, like it, a life history. Some are now in their infancy; others in the full vigour of their development; and others in their decline. For ourselves, I think, as life advances, there is nothing unpleasing in the thought of death. To the man who humbly trusts in God, the thought of death is natural and pleasing, and his feelings in regard to it may be expressed in the words of the great Cid Campeador—

> "Friends, I sorrow not to leave you;
> If this life an exile be,
> We who leave it do but journey
> Homeward to the family."

"Thalès, arrivée 585 ans avant J.-C., a été vue en Asie Mineure; sans le "ralentissement du mouvement de rotation de la terre, on l'aurait vue dans "l'île de Sardaigne.

"Celle de Larissa (557 ans avant J.-C.) a été observée en Perse; on "l'aurait vue dans la régence de Tripoli, sans le ralentissement.

"Enfin, celle d'Agathocle (310 ans avant J.-C.), signalée près de Syra- "cuse, aurait dû se montrer près de Cadix."

LECTURE II.*

CONTINENTS AND OCEANS, VOLCANOES AND MOUNTAINS.

LADIES AND GENTLEMEN,

In my last Lecture, I should have explained to you why the changes in the life history of the moon have taken place with so much greater rapidity than those in the life history of the earth. In the first place, all changes depending on loss of heat will take place more rapidly in a small body than in a large one, and as the mass of the earth is eighty times greater than that of the moon, we should not be surprised to find that the moon has cooled down beyond the stage yet reached by the earth; and in the second place, the tidal friction caused by the earth tide on the surface of the moon will, *cæteris paribus*, be greater than the friction caused by the lunar tide produced in the terrestrial oceans, in the proportion of the mass of the earth to that of the moon.

The water and atmosphere that, doubtless, once clothed the surface of the moon, lasted sufficiently long to reduce her rotatory motion to a minimum, so that her day is now equal to her periodic revolution round the earth; but that

* This Lecture was delivered on the 11th of March, 1876.

water and atmosphere have now almost, if not altogether, disappeared. We can guess at the causes of the total disappearance of the moon's ocean and atmosphere, by observing what takes place on our own planet, in the interior of metallic lodes. The water of the surface, and the carbonic acid and oxygen of the atmosphere, enter into chemical combination with the metallic and earthy bases, and all such combined oxygen and water is locked up for ever and disappears from the atmosphere and ocean.*

From what has been already stated, it appears probable that the earth was originally formed by the union of multitudes of meteoric stones and meteoric iron into a solid globe, the contraction of such meteorites into a central body being, necessarily, accompanied with the development of much heat. Some are of opinion that the internal heat of the globe increases continuously with the depth, so that at a comparatively trifling depth, of from 20 to 30 miles, the heat would be sufficient to fuse all the rocks known at the surface. I am, however, inclined to think that there are hotter and colder layers as we proceed into the interior of the globe, and that there may even be layers intensely cold, corresponding with the intense cold of interplanetary space, which has been proved to be 250° F. below the freezing point of water.

Whatever be the exact thermal condition of the interior of the earth, it is certain that, as a whole, she has cooled down from a condition formerly much hotter than

* It has been estimated by some mineralogists that a quantity of water equal to, possibly, one-third of the bulk of the ocean has been already absorbed by hydrated minerals. This estimate is considered much too high by Professor Dana, who supposes the absorbed water to be only equal to 400 ft. difference in the sea level.

the present, and in doing so has undergone contraction proportionate to the loss of heat.

The mechanical effects of this contraction are probably the cause of all the corrugations visible on the surface of the earth, such as continents and oceans, mountain chains and deep-sea valleys; and produce, also, the phenomena exhibited by volcanoes.

It is my intention to give you a short outline of these subjects in the present Lecture.

We know from a study of the continents, that their mean height is small in comparison with that of the mountain chains, which compose their axis or skeleton; and although the form of the ocean bottoms is less known to us, we have reason to believe that they are flatter than the surface of the land—presenting, however, long deep-sea valleys, which are the counterparts of the mountain chains.

Our first inquiry is as to the general position and character of the mountain chains and deep-sea valleys which form the axes of the continents and oceans; and we shall commence with the Southern Hemisphere, which is more symmetrical and less complex than the Northern.

From all the evidence that has been collected respecting the South Pole, it appears that a great continent exists there, covered with perpetual ice, which flows from the higher land in the interior outwards to the coast line, where it forms the celebrated "Ice-barrier," from which a continuous supply of icebergs is furnished to the Antarctic Ocean. Great mountains exist in the South Polar Land, within 800 or 900 miles from the pole, including the active volcano Erebus, 12,366 feet in height, and Mount Terror, 13,884 feet in height.

The structure of the Southern Hemisphere is shown in Fig. 3, in which the lines A represent meridians of depression, and the lines B meridians of elevation. The meridians of depression are—

A. South Pacific Ocean.
B. South Atlantic Ocean.
C. Indian Ocean.

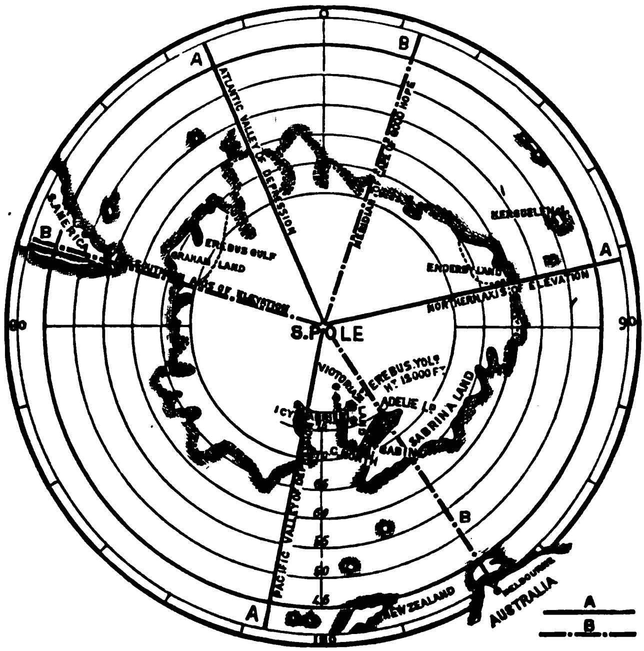

Fig. 3.

The intervening meridians of elevation are—

D. South America.
E. Africa.
F. Eastern Australia.

It will be seen from Fig. 3 that the meridians of elevation and depression succeed each other alternately, and with a considerable approach to symmetry.

The mean depth of the valleys of ocean depression has been estimated by the rate of motion of earthquake and tidal waves, and also by direct soundings. All the methods agree in giving a mean depth of more than two geographical miles, or 12,000 feet.

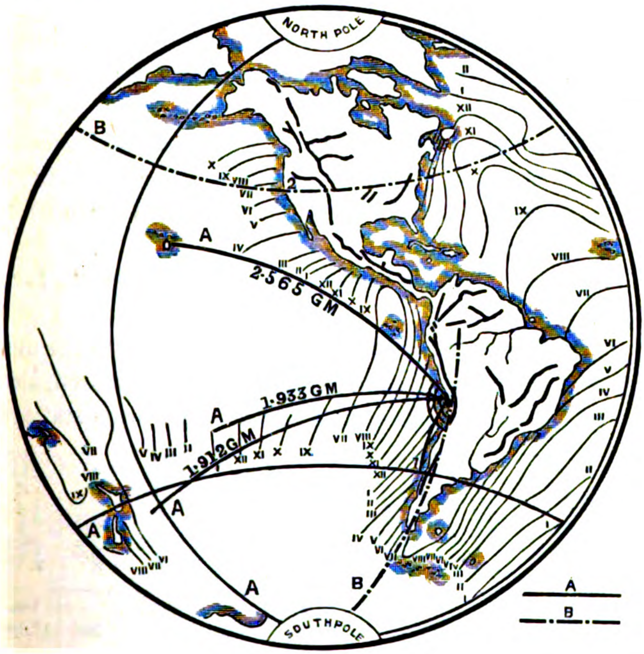

Fig. 4.

A. **South Pacific Depression.**—On the 13th August, 1868, an earthquake occurred, vertically under the town of Arica, a seaport in Peru, and was followed by a great sea-wave that travelled nearly across the Pacific Ocean, in all directions. The first shock of the earthquake occurred at Arica at 5^h 5^m, and lasted till 5^h 15^m; and the first wave commenced at 5^h 32^m. The times of the arrival of the great sea-wave were observed at many stations, the distances of which from Arica are known;—and from these data were calculated, by the usual methods, the mean ocean depth of the path traversed by the sea-wave. Among the stations in the South Pacific, where the Arica sea-wave was observed, there were—

1. *The Navigator's or Samoa Islands.* Lat. 14° S., Long. 170° W.—These islands lie somewhat to the north of west from Arica.

2. *The Islands of Oparo and Rapa* (*Austral Islands*). Lat. 27° S., Long. 145° W.—These islands lie to the south of west from Arica, in a direction a little to the north of New Zealand.

3. *Chatham Island* (*New Zealand*). Lat. 54° S., Long. 180°.

The following Table shows the data from which the mean depth of the South Pacific Ocean has been calculated, along the great circles leading from Arica to the three stations.*

STATION.	Distance from Arica.	Local Time, First wave.	Longitude from Arica.	Arica Time, First wave.	Time of transmission.	Nautical Miles per hour.	Mean depth of Ocean in feet.
	miles.	d. h. m.	h. m.	d. h. m.	h. m.		feet.
Navigator's Islands,	5760	14 14 30	6 40	13 21 10	15 38	368	12,100
Austral Islands,	4057	13 11 30	4 56	13 16 26	10 54	372	12,200
N. Zealand,	5520	14 13 30	7 3	13 20 33	15 1	368	12,100
Mean depth, ... 12,134 feet.							

* Hilgard (Coast Survey, U.S.A.): "American Journal of Science," vol. vi., third series, p. 77.

The numbers marked with Roman letters in Fig. 4 are co-tidal lines, which mark approximately the depth of the ocean, as the depth increases with the distance between the lines; and three of the Arica lines are also shown, with mean depths, in geographical miles.

The depth of the South Pacific Ocean, obtained from deep soundings, may be thus estimated* :—

*I.—*Sydney* (*Australia*) *to N. Zealand* (35° S.–40° S.)

1.	2·200 G. M.
2.	2·600 ,,
3.	2·600 ,,
4.	1·975 ,,
Mean depth,	**2·344** G. M. = **14,064** feet.

*II.—*New Zealand*, viâ *Fiji Is. to Cape York* (*Australia*) (40° S.–12° S.)

1.	1·100 G. M.	7.	2·450 G. M.
2.	2·900 ,,	8.	2·440 ,,
3.	1·350 ,,	9.	2·275 ,,
4.	1·450 ,,	10.	1·700 ,,
5.	2·650 ,,	11.	1·400 ,,
6.	2·325 ,,		

Mean depth, . . . **2·002** G. M. = **12,008** feet.

*III.—*Otaheite to Valparaiso* (20° S.–35° S.)

1.	1·940 G. M.	11.	2·300 G. M.
2.	2·385 ,,	12.	2·250 ,,
3.	2·450 ,,	13.	1·600 ,,
4.	2·075 ,,	14.	2·025 ,,
5.	1·985 ,,	15.	2·270 ,,
6.	2·375 ,,	16.	1·500 ,,
7.	2·335 ,,	17.	1·825 ,,
8.	2·400 ,,	18.	1·775 ,,
9.	2·600 ,,	19.	2·225 ,,
10.	2·550 ,,		

Mean depth, . . . **2·148** G. M. = **12,888** feet.

* These figures are taken from the Cruise of H. M. S. "Challenger."—"Proc. R. S.," vol. xxiv., pp. 463-636.

Combining the results together, we obtain—

Mean Depth of South Pacific Ocean.

I.—Sydney to New Zealand, ...	14,064 feet.
II.—New Zealand to Fiji, ...	12,008 „
III.—Otaheite to Valparaiso, ...	12,888 „
Mean depth, ...	**12,987** feet.

This result, obtained with such labour, from direct soundings, agrees well with that already obtained by calculation, from a few moments' observation of the sea-wave caused by the Arica earthquake,* viz., **12,134** feet.

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* This example of the Arica earthquake sea-wave shows the value of what may be called *Critical Observations* in saving time and labour in the investigation of truth.

A most remarkable instance of *Critical Observation* has recently occurred, in consequence of the discovery of the two moons of Mars, which it is proposed to call Romulus and Remus. It is well known that the mass of a planet can be instantly determined, if the planet has a moon whose distance and periodic time are known.

Leverrier spent upwards of ten years in determining the masses of the planets not attended by moons, viz., Mars, Venus, and Mercury, from their disturbing influence on the orbits of other planets; and obtained for Mars—

$$\text{mass of Mars} = \frac{\text{mass of Sun}}{3,000,000}.$$

When a planet has a moon, the following equation gives the ratio of the mass of the planet to the mass of the sun—

$$\frac{\text{mass of Sun}}{\text{mass of Planet}} = \frac{R^3}{T^2} \times \frac{t^2}{r^3},$$

where

R is the distance of planet from sun,
T „ periodic time of planet,
r „ distance of moon from planet,
t „ periodic time of moon.

Applying this formula to the case of Mars and Romulus, from the following data:—

Mars.	*Romulus.*
R = 121,000,000 miles,	r = 12,483 miles,
T = 687 days,	t = 1·2627 days,

we find—

$$\text{mass of Mars} = \frac{\text{mass of Sun}}{3,077,000}.$$

B. **South Atlantic Depression.**—The mean depth of the South Atlantic Ocean may be found from the following soundings made by the "Challenger":—

*I.—*Falkland Islands to Monte Video* (50° S.–35° S.)

1.	1·035 G. M.
2.	2·040 ,,
3.	2·425 ,,

Mean depth, . . . **1·833** G. M. = **11,000** feet.

*II.—*Monte Video to Tristan da Cunha* (35° S.–40° S.)

1. . . .	1·900 G. M.	8. . . .	2·440 G. M.
2. . . .	2·800 ,,	9. . . .	1·715 ,,
3. . . .	2·650 ,,	10. . . .	2·200 ,,
4. . . .	2·775 ,,	11. . . .	2·025 ,,
5. . . .	2·900 ,,	12. . . .	1·915 ,,
6. . . .	2·900 ,,	13. . . .	1·425 ,,
7. . . .	2·675 ,,	14. . . .	1·890 ,,

Mean depth, . . . **2·301** G. M. = **14,806** feet.

*III.—*Bahia* (viâ *Tristan da Cunha*) *to Cape of Good Hope* (20° S.–35° S.)

1. . . .	2·150 G. M.	6. . . .	2·025 G. M.
2. . . .	2·350 ,,	7. . . .	2·100 ,,
3. . . .	2·275 ,,	8. . . .	2·550 ,,
4. . . .	2·050 ,,	9. . . .	2·650 ,,
5. . . .	1·900 ,,	10. . . .	2·325 ,,

Mean depth, . . . **2·2375** G. M. = **13,425** feet.

Combining these results together, we obtain—

Mean Depth of South Atlantic Ocean.

I.—Falkland Islands to Monte Video, . . .	11,000 feet.
II.—Monte Video to Tristan da Cunha, . . .	14,806 ,,
III.—Bahia (*viâ* Tristan da Cunha) to Cape of Good Hope, ...	13,425 ,,

Mean depth, ... **13,077** feet.

* See note, p. 23.

C. **South Indian Depression.**—The mean depth of the third southern axis of depression may be thus found:—

*I.—*Cape of Good Hope* (viâ *Kerguelen*) *to Melbourne* (*Australia*) (35° S.–60° S.)

1. . . .	1·800 G.M.	8. . . .	1·300 G.M.
2. . . .	1·570 ,,	9. . . .	1·975 ,,
3. . . .	1·510 ,,	10. . . .	1·950 ,,
4. . . .	1·375 ,,	11. . . .	1·800 ,,
5. . . .	1·600 ,,	12. . . .	2·150 ,,
6. . . .	1·260 ,,	13. . . .	2·600 ,,
7. . . .	1·675 ,,	14. . . .	2·200 ,,

Mean depth, . . . **1·769** G.M. = **10,610** feet.

We thus find, for the mean depths of the three southern valleys of depression—

A.	South Pacific, ...	**12,987** feet.
B.	South Atlantic,. . . .	**13,077** ,,
C.	South Indian, ...	**10,610** ,,

The agreement between the first two of these mean depths is very remarkable, and it is highly probable that the defect of the third is due to a deficiency of observations. The soundings in the South Indian Ocean were taken, in many cases, in the neighbourhood of islands; and we have reason from tidal phenomena to believe that the Indian Ocean, from Madagascar to Australia, and from Kerguelen to Ceylon, is at least as deep as either the South Pacific or South Atlantic Ocean.

Let us now examine the meridian axes of elevation of the Southern Hemisphere:—

D. **South American Axis of Elevation.**—This axis of elevation has produced the continent of South America, and the axis itself is represented by the mountain chain

* See note, p. 23.

of the Andes, which extends from south to north along the western coast of South America, for a length of 5000 miles, and contains many important mountain summits, mostly of volcanic origin. The chief of these are—

1. Carguairazo,	. . . . .	15,673 feet.
2. Chimborazo,	. . . . .	21,700 „
3. Cotopaxi,*	. . . . .	18,877 „
4. Antisana,*	. . . . .	19,137 „
5. Pichincha,*	. . . . .	15,923 „
6. Aconcagua,	. . . . .	23,910 „

The total mass of the mountain axis is two-fifths of the total mass of the entire continent. If the Andes could be spread over the whole surface of South America, that continent would be raised 924 feet in height.†

E. **African Axis of Elevation.**—This axis of elevation has produced the continent of Africa, which consists of an elevated table-land in the south, and of a low-lying desert (Great Sahara) in the north. The mountain axis follows the meridian along the east coast of Africa, attaining its greatest heights in the equatorial ranges that feed the Albert and Victoria Nyanzas, and in Abyssinia. The chief summits are—

* These three mountains are subaerial volcanoes, and there is reason to believe that subaerial volcanoes in the same district ultimately attain the same height, depending on the volcanic energy of the district; if this be correct, we conclude that Cotopaxi, Antisana, and Pichincha, have nearly reached their full growth, and that their volcanic energy is measured by the power of lifting lava to a height of 18,000 feet. We shall afterwards see that the energy of European volcanoes is only two-thirds of this, or 12,000 feet.

† These results can be readily deduced from the following data:—

The area of South America is	6,800,000 square miles.	
„ „ Andes „	531,000 „ „	
Mean height of S. America „	1,151 feet.	
„ „ Andes „	11,830 „	

1.	Kenia, ...	20,000	feet.
2.	Kilima Ndjaro, . . .	21,000	„
3.	Mount Woso, ...	16,350	„
4.	Mount Dajan, ...	15,740	„
5.	Abba Jarrat, ...	15,008	„
6.	Geesh, ...	15,000	„
7.	Buahat, ...	14,362	„
8.	Mount Fatra, ...	14,350	„

The mean height of Africa above the sea level is estimated at about 900 feet by Sir John Herschel,

F. **Australian Axis of Elevation.**—This axis of elevation is much less marked than those of South America and Africa. The entire continent has a much lower elevation than that of any other continent. The meridian mountain axis is represented by the New Zealand Islands, and by a parallel chain running north and south on the east coast of Australia.

The New Zealand chain contains—

1.	Mount Cook, ...	13,200	feet.
2.	Mount Franklin, . . .	10,000	„
3.	Mount Edgecumbe, . .	9,195	„
4.	Mount Egmont, . . .	8,270	„

and the Eastern Australian chain contains—

5.	Mounts Hotham and Kosciusko, . . .	7,000	„
6.	Mount Lindsay, . . .	5,700	„

The interior of Australia, like the northern part of Africa, seems to be an ancient sea-bed, from which the ocean has receded, on the elevation of the continent.

When we turn from the Southern Hemisphere to the

Northern, we find it constructed on a different type with respect to meridian axes of elevation and depression.

There are two axes of elevation and two axes of depression, instead of three each, as in the Southern Hemisphere.

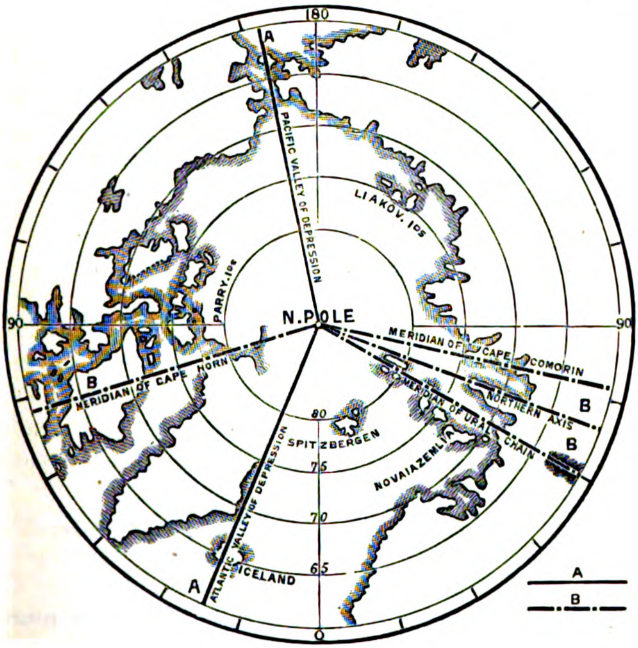

Fig. 5.

The meridians of depression are—

G. North Pacific Ocean.
H. North Atlantic Ocean.

The intervening meridians of elevation are—

I. North America.
K. Great Continent (Europasia).

The structure of the Northern Hemisphere is shown in Fig. 5, in which the lines A denote meridian axes of depression, and the lines B denote meridian axes of elevation.

The North Pole is surrounded by a circumpolar basin, probably an archipelago, bounded by the northern shores of Europe and Asia, of North America and Greenland—and forms in this respect a marked contrast to the South Pole, which is the centre of a large continent, containing lofty volcanic mountains, such as—

1.	Mount Terror, ...	13,884 feet.
2.	Mount Erebus, ...	12,366 ,,

G. **North Pacific Depression.**—The North Pacific Ocean opens into the circumpolar sea by the shallow depression of Behring's Straits, which is not more than 25 fathoms deep, but the ocean rapidly deepens as we go southwards.

Its mean depth has been ascertained by means of earthquake sea-waves, and by direct soundings.

The Arica sea-wave, already noticed, was observed at the following places :—

1. *San Diego* (*California*). Lat. 32° N.—The course taken by the wave was north-westwards, and close along the American coasts. This measurement is very important as showing the deep soundings which occur close to the western coasts of both Americas.

2. *Fort Point* (*Astoria*). Lat. 46° N.—The same remark applies to this locality.

3. *Owhyhee* (*Sandwich Islands*). Lat. 20° N.

4. *Honolulu* (*Sandwich Islands*). Lat. 20° N.

The following Table contains the results—

Station.	Distance from Arica.	Local Time, First wave.	Longitude from Arica.	Arica Time, First wave.	Time of transmission.	Nautical Miles per hour.	Mean depth of Ocean in feet.
	miles.	d. h. m.	h. m	d. h. m.	h. m.		feet.
San Diego,	4030	13 14 0	2 27	13 16 27	10 55	369	12,100
Fort Point,	4480	13 15 0	3 28	13 18 28	12 56	348	10,800
Owhyhee, .	5460	13 14 0	5 42	13 19 42	14 10	385	13,200
Honolulu, .	5580	13 12 0	5 50	13 17 50	12 18	454	18,500
Mean depth, ... **13,650** feet.							

We have, also, on record an earthquake sea-wave that enables us to measure the mean depth of the whole North Pacific Ocean, from Japan to California.

On the 23rd December, 1854, a terrible earthquake occurred in Japan, which caused great waves to travel across the entire breadth of the North Pacific Ocean, on the parallel of 34° N., from Simolo, in Japan, to San Francisco and San Diego, in California, where the sea-waves were recorded on the self-registering tide gauges.

The sea-wave was 217 miles in width, and was propagated through 4,527 miles at an average rate of 6·1 miles per minute; from these data, Professor Bache deduced a mean depth of 14,190 feet. Combining together all the calculations made from earthquake sea-waves, we find the following mean depth of the North Pacific Ocean:—

1. Arica to San Diego, ... 12,100 feet.
2. Arica to Fort Point, ... 10,800 „
3. Arica to Owhyhee, ... 13,200 „
4. Arica to Honolulu, ... 18,500 „
5. Japan to California, ... 14,190 „

Mean depth, ... **13,758** feet.

The deep-sea soundings made by the "Challenger" in the Equatorial and North Pacific are given in the following Tables :—

*I.—*Cape York* (*Australia*) *to Japan* (viâ *Celebes, Sulu, and China Seas*) (10° S.–35° N.)

1.	2·800 G.M.	16.	1·100 G.M.
2.	1·425 ,,	17.	2·650 ,,
3.	1·200 ,,	18.	2·450 ,,
4.	2·150 ,,	19.	2·325 ,,
5.	2·600 ,,	20.	1·850 ,,
6.	2·550 ,,	†21.	4·575 ,,
7.	1·050 ,,	†22.	4·475 ,,
8.	2·100 ,,	23.	2·300 ,,
9.	2·225 ,,	24.	2·475 ,,
10.	2·050 ,,	25.	2·450 ,,
11.	2·550 ,,	26.	2·500 ,,
12.	1·675 ,,	27.	2·425 ,,
13.	2·000 ,,	28.	2·250 ,,
14.	2·000 ,,	29.	2·675 ,,
15.	1·075 ,,		

Mean depth, . . . **2·274** G.M. = **13,645** feet.

*II.—*Japan to Sandwich Islands* (35° N.–20° N.)

1.	1·875 G.M.	12.	3·000 G.M.
2.	3·900 ,,	13.	3·050 ,,
3.	3·625 ,,	14.	2·900 ,,
4.	2·900 ,,	15.	2·740 ,,
5.	2·300 ,,	16.	3·125 ,,
6.	2·575 ,,	17.	3·025 ,,
7.	2·800 ,,	18.	2·850 ,,
8.	2·900 ,,	19.	2·950 ,,
9.	2·775 ,,	20.	2·875 ,,
10.	2·530 ,,	21.	2·775 ,,
11.	2·900 ,,	22.	2·225 ,,

Mean depth, . . . **2·845** G.M. = **17,070** feet.

* See note, p. 23.

† Lat. 11° 24′ N., Long. 143° 16′ E. South of the Marian or Ladrone Islands.

*III. — *Sandwich Islands to Society Islands (Otaheite)* (20° N.–20° S.)

1. . . .	2·050 G.M.	10. . . .	2·925 G.M.
2. . . .	2·875 ,,	11. . . .	2·425 ,,
3. . . .	2·650 ,,	12. . . .	2·600 ,,
4. . . .	3·000 ,,	13. . . .	2·350 ,,
5. . . .	2·900 ,,	14. . . .	2·750 ,,
6. . . .	2·750 ,,	15. . . .	2·610 ,,
7. . . .	2·700 ,,	16. . . .	2·350 ,,
8. . . .	2·900 ,,	17. . . .	2·325 ,,
9. . . .	2·550 ,,	18. . . .	1·525 ,,

Mean depth, . . . **2·569** G.M. = **15,414** feet.

*IV.—*Line of Soundings, passing through the Sandwich Islands, from a point* 700 *miles to the West to another* 2000 *miles to the E. N. E.*

1. . . .	2·460 G.M.	9. . . .	2·982 G.M.
2. . . .	2·794 ,,	10. . . .	2·841 ,,
3. . . .	2·733 ,,	11. . . .	2·618 ,,
4. . . .	2·555 ,,	12. . . .	2·628 ,,
5. . . .	2·418 ,,	13. . . .	2·159 ,,
6. . . .	2·726 ,,	14. . . .	2·541 ,,
7. . . .	3·053 ,,	15. . . .	2·323 ,,
8. . . .	2·982 ,,	16. . . .	2·587 ,,

Mean depth, . . . **2·650** G.M. = **15,900** feet.

Combining these results together, we find for the—

Mean Depth of the North Pacific Ocean.

I.—Australia to Japan, ...	13,645 feet.
II.—Japan to Sandwich Islands, ...	17,070 ,,
III.—Sandwich Islands to Otaheite, ...	15,414 ,,
IV.—From 700 m. West of Sandwich Islands to 2,000 m. E.N.E., ...	15,900 ,,

Mean depth, ... **15,507** feet.

* See note, p. 23.

This agrees very well with the mean of the two values of the mean depth from Arica to the Sandwich Islands obtained (p. 31) by means of the earthquake sea-wave, viz.:—

1.	13,200 feet.
2.	18,500 ,,

Mean depth, . . **15,850** feet.

H. **North Atlantic Depression.**—The mean depth of the North Atlantic Ocean, may be found from the following soundings:—

*I.—*New York to Gibraltar* (viâ *Bermuda, Azores, and Madeira*) (30°–40° N.)

1. . . .	1·250 G.M.	19. . . .	2·100 G.M.
2. . . .	1·700 ,,	20. . . .	1·675 ,,
3. . . .	2·423 ,,	21. . . .	1·675 ,,
4. . . .	1·650 ,,	22. . . .	1·240 ,,
5. . . .	2·615 ,,	23. . . .	1·000 ,,
6. . . .	2·800 ,,	24. . . .	1·350 ,,
7. . . .	2·600 ,,	25. . . .	1·000 ,,
8. . . .	2·650 ,,	26. . . .	2·025 ,,
9. . . .	2·200 ,,	27. . . .	2·660 ,,
10. . . .	2·560 ,,	28. . . .	2·875 ,,
11. . . .	2·575 ,,	29. . . .	2·400 ,,
12. . . .	2·850 ,,	30. . . .	1·600 ,,
13. . . .	2·875 ,,	31. . . .	2·225 ,,
14. . . .	2·750 ,,	32. . . .	2·250 ,,
15. . . .	2·700 ,,	33. . . .	2·125 ,,
16. . . .	2·750 ,,	34. . . .	1·525 ,,
17. . . .	2·700 ,,	35. . . .	1·090 ,,
18. . . .	2·175 ,,		

Mean depth, . . . **2·132** G.M. = **12,795** feet.

* See note, p. 23.

*II.—*St. Thomas* (*W. Indies*) *to Teneriffe* (20° N.–30° N.)

1. . . .	1·420 G.M.	11. . . .	2·575 G.M.
2. . . .	3·025 ,,	12. . . .	2·220 ,,
3. . . .	2·975 ,,	13. . . .	3·150 ,,
4. . . .	3·000 ,,	14. . . .	2·800 ,,
5. . . .	2·675 ,,	15. . . .	2·750 ,,
6. . . .	2·385 ,,	16. . . .	2·950 ,,
7. . . .	2·435 ,,	17. . . .	2·720 ,,
8. . . .	2·325 ,,	18. . . .	2·220 ,,
9. . . .	1·950 ,,	19. . . .	1·945 ,,
10. . . .	2·025 ,,		

Mean depth, . . . 2·502 G.M. = 15,012 feet.

*III.—*Madeira to Bahia* (viâ *Teneriffe, Cape de Verde Islands, and Sierra Leone Coast*) (30° N.–15° S.)

1. . . .	1·975 G.M.	14. . . .	2·450 G.M.
2. . . .	1·890 ,,	15. . . .	2·475 ,,
3. . . .	1·525 ,,	16. . . .	2·500 ,,
4. . . .	2·300 ,,	17. . . .	2·275 ,,
5. . . .	2·400 ,,	18. . . .	1·850 ,,
6. . . .	2·400 ,,	19. . . .	1·500 ,,
7. . . .	2·025 ,,	20. . . .	1·900 ,,
8. . . .	1·973 ,,	21. . . .	2·275 ,,
9. . . .	2·300 ,,	22. . . .	2·475 ,,
10. . . .	2·575 ,,	23. . . .	2·250 ,,
11. . . .	1·730 ,,	24. . . .	2·150 ,,
12. . . .	2·425 ,,	25. . . .	1·375 ,,
13. . . .	2·300 ,,	26. . . .	1·650 ,,

Mean depth, . . . 2·113 G.M. = 12,680 feet.

*IV.—*Nova Scotia to St. Thomas* (*W. Indies*) (45° N.–20° N.)

1. . . .	1·250 G.M.	7. . . .	2·600 G.M.
2. . . .	2·020 ,,	8. . . .	2·700 ,,
3. . . .	2·800 ,,	9. . . .	2·850 ,,
4. . . .	2·650 ,,	10. . . .	2·960 ,,
5. . . .	2·650 ,,	11. . . .	2·800 ,,
6. . . .	2·500 ,,	12. . . .	3·675 ,,

Mean depth, . . . 2,621 G.M. = 15,725 feet.

* See note, p. 23.

†V.—*Ireland to Labrador* (51° N.–63° N.)

H.M.S. "Bulldog."	H.M.S. "Valorous."	H.M.S. "Porcupine."
1. . . . 1·260 G.M.	1. . . . 1·785 G.M.	1. . . . 1·470 G.M.
2. . . . 1·168 ,,	2. . . . 1·485 ,,	
	3. . . . 1·230 ,,	
	4. . . . 1·450 ,,	
	5. . . . 1·860 ,,	
	6. . . . 1·660 ,,	
	7. . . . 1·750 ,,	
	8. . . . 1·350 ,,	
	9. . . . 1·100 ,,	

Mean depth, . . . **1·464** G.M. = **8,784** feet.

This result shows that the North Atlantic Ocean becomes more shallow in the high northern latitudes. In the North Pacific Ocean, also, the water becomes more shallow in the high northern latitudes approaching Behring's Straits.

Bringing these results together, we obtain for the mean depth of the southern and equatorial parts of the North Atlantic :—

I.—New York to Gibraltar, ...	12,795 feet.
II.—St. Thomas to Teneriffe, ...	15,012 ,,
III.—Madeira to Bahia, ...	12,680 ,,
IV.—Nova Scotia to St. Thomas, ...	15,725 ,,
Mean depth, ...	**14,053** feet.

Mean depth of the northern portion of the North Atlantic Ocean :—

V.—Ireland to Labrador, ... **8,784** feet.

† *Proc. R. S.*, vol. xxv., pp. 177–237.

Let us now examine the meridian axes of elevation of the Northern Hemisphere:—

I. **North American Axis of Elevation.**—This axis has produced the continent of North America, and the axis itself is represented by the Rocky Mountains, extending from N.N.W. to S.S.E., from 65° N. to the table-land of Mexico, 25° N., through 3000 miles of length. The most important summits of this great axis are—

1.	Mount St. Elias, ...	14,970 feet.
2.	Mount Fairweather, . .	14,712 „
3.	Mount Brown, ...	15,990 „
4.	Mount Hooker, ...	16,730 „
5.	Fremont's Peak, ...	13,568 „

North and South America are constructed on the same type, viz. :—a mountain axis, or parallel axes, running in a northerly and southerly direction, close to the west coast, and a large, comparatively flat area, lifted above the sea level to an average height of somewhat less than 500 feet. Humboldt estimates the *maximum* possible mean height of North America, including the Rocky and Mexican Mountains and table-lands, at 748 feet.

The South American and North American axes of elevation do not occur on the same meridian, the South American chain being from 20° to 30° to the eastward of the mean meridian of the Rocky Mountains.

The two great meridian chains are connected by a range running from west to east and south-easterly, composed of the Mexican volcanic axis and Central America.

Mexican Volcanic Axis and West Indies.

This remarkable axis runs from west to east, and cuts across the meridian chain almost at right angles. It contains the following volcanic summits :—

1. Colima,	12,000	feet.
2. Toluca,	15,542	„
3. Popocatapetl,	17,717	„
4. Iztacihuatl,	15,705	„
5. Orizaba,	17,374	„

This chain is of recent date, as compared with the meridian axis of North America ; and it may be regarded as prolonged eastward through Cuba, Jamaica, and Haiti, afterwards turning to the south through the Windward Islands. The most important summits of the West Indian, or submarine, portion of the chain, are :—

6. Cuba,	7,200	feet.
7. Jamaica,	7,150	„
8. Haiti,	8,900	„
9. Dominica,	5,318	„
10. Guadaloupe,	5,113	„

Central American Axis.

The Central American axis runs from Mexico to the south-east until it meets, at the Isthmus of Panama, the western chain of the Andes, which blends with it. At this point, also, the eastern chain of the Andes, ceasing its parallelism, curves round with a circular sweep to the eastward, and forms the coast chain of Venezuela, terminating finally in the island of Trinidad, where it meets the termination of the Mexican axis.

The Central American portion of the axis consists of a range of lofty volcanoes, of which the highest is Agua (13,000 feet); and the intersection of this east and west chain with the meridian chain of the Andes may be considered as marked by the Sierra Nevada of Santa Marta (19,000 feet) near Cape St. Juan, on the Caribbean Sea.

The Gulf of Mexico and the Caribbean Sea, hemmed in between these two south-eastern axes, present many analogies to our own Mediterranean Sea, which is enclosed by the eastern axes of the Atlas Mountains, and of the Pyrenees, Alps, Balkan, and Taurus. Even the division of the Mediterranean into two deep portions, by Italy and Sicily, is imitated in the separation of the Gulf of Mexico and the Caribbean Sea by the peninsula of Yucatan.

The general relations of North and South America to their mountain axes are shown in Fig. 4.

K. **Europasian Axes of Elevation.**—The relations of the Great Continent to its mountain axes of elevation are much more complicated than those of the other continents; and this arises from the fact that a great axis of elevation, running from east to west, disguises the primary features of the meridian chain.

The general relations of Europasia, Africa and Australia to their mountain chains are shown in Fig. 6, which will assist the following descriptions:—

Meridian Chains of Europasia.

The Uralian Chain.—The meridian chain of Europasia commences near the North Pole in Franz-Joseph Land,

and is continued south, through Nova Zembla, into the Ural Mountains, which terminate to the north-east of the Caspian Sea. This chain runs due north and south, and is upwards of 2000 miles in length.

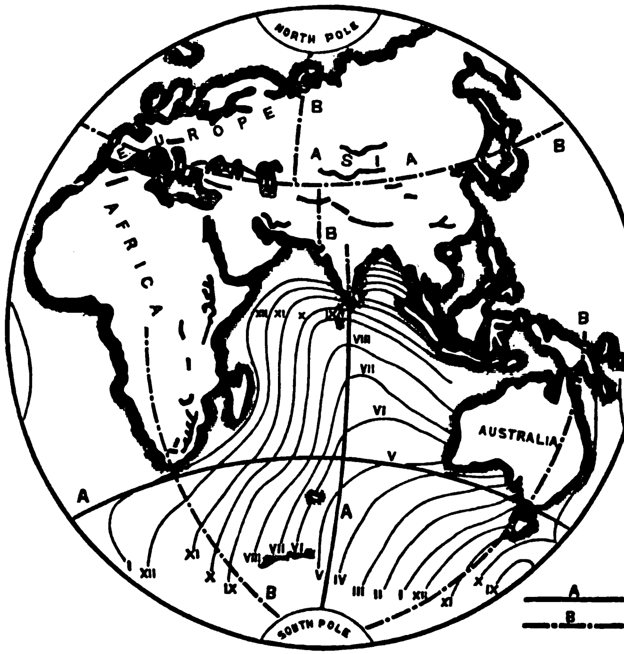

Fig. 6.

The Bolor Chain.—The next meridian chain is that of the Bolor, which runs from the east of the sea of Aral into Cashmere, a distance of 800 miles. The Bolor range intersects the great east and west chain, in a mountain mass, called by the Chinese the *Knot of Tsung Ling*, south-west of Yarkand. This intersection of the meridian axis with the east and west axis of Europasia is called by the natives *Baam i Dunja*, which means The Roof of the

World. The direction of the Bolor range is S.S.E., and it is to be noted that it commences in the latitude where the Ural range terminates, at about 500 miles to the eastward.

The Solymaun Chain.—This meridian chain starts abruptly from a point in the great east and west chain 90 miles westward of the *Baam i Dunja*—and the two meridian chains present all the appearance of having been "heaved" (as Cornish miners would say) by the east and west chain, through a distance of 90 or 100 miles. The Solymaun range runs S. S. W. from its origin in the Hindoo Koosh (for a distance of about 700 miles) to the north of the mouth of the Indus.

The Western Ghauts.—This range extends for 900 miles, running S. S. E. along the west coast of India, and terminates in the lofty granite peaks of Ceylon.

It is quite possible that these four ranges may have once formed one meridian axis of elevation, upwards of 3000 miles in length, and that this axis of elevation may have been dislocated into four by the subsequent upheavals of the several parallel east and west chains which constitute the chief peculiarity of Europasia. The principal summits in the four ranges are :—

1. Franz-Joseph Land, . .	4,000	feet.
2. Nova Zembla, ...	3,472	„
3. Deneskin Kamen, . . .	5,387	„
4. Sir-i-Kol (Lake)*, . . .	15,600	„
5. Solymaun, ...	12,150	„
6. Chira-gab, ...	9,941	„
7. Adam's Peak, ...	6,650	„
8. Pedrotallagalla, ...	8,280	„

* The highest lake in the world; source of the Amu Daria (Oxus).

East and West Mountain Chains of Europasia.

These form the most wonderful mountain chains on the surface of the globe, and may be regarded as extending through the entire width of the continent, from Spain on the west to China on the east.

The Kuenlun, or *Central Chain*, extends over 64° of longitude, from the south of the Caspian to the sea-coast of China—a distance of 3500 miles—on a small circle of latitude; and no part of the range deviates more than 2° from the parallel of 35° 30′.

The Central chain may be regarded as extending westwards also from the Caspian Sea to the Pyrenees, in a more or less connected series of parallel east and west ranges, for an additional 3000 miles. The chief summits of the entire range, reckoned from west to east, are :—

1. Pic Nethou (Pyrenees),	. 11,168	feet.
2. Mont Blanc (Alps), . . .	. 15,810	„
3. Elbruz (Caucasus), . . .	. 17,796	„
4. Ararat (Taurus), ...	. 17,210	„
5. Demavend (Caspian), . .	. 14,660	„
6. Baam i Dunja, ...	. 17,900	„

To the east of the "Roof of the World," the Central or Kuenlun chain is prolonged into China, under the names, Aneutun, Kulkun, Tapa-ling, and Mu-ling.

In Asia, two parallel chains run to the northward of the Central chain, viz.:—the Thianshan and Altai mountains; and one parallel chain to the southward, the Himalaya chain.

The Thianshan Chain.—This chain lies about 500 miles to the north of the Kuenlun chain, and is prolonged into China by the Shan Gárjan chain. It is said to contain two volcanoes, Pe-shan and Ho-tcheou, but this requires confirmation. This range extends for a distance of 1100 miles.

The Altai Chain.—This parallel range lies to the north and east of the Thianshan range, and often attains an altitude of 11,000 feet.

The Himalaya Chain lies to the south of the Kuenlun range, which it joins by a north-western branch, at Kuttore, and they inclose between them the lofty tablelands of Cashmere and Thibet. The chief summits of the Himalaya range are :—

1. Jumnotri, ...	25,669	feet.
2. Nanda-devi, ...	25,749	„
3. Dwalagiri, ...	27,600	„
4. Kinchin junga, ...	28,178	„
5. Mount Everest (Deodunga),	29,002	„

The total length of the Himalaya chain is 1300 miles, and it comprises within its range at least 40 peaks exceeding Chimborazo in height, and has a mean altitude of about 18,000 f et.

In describing the structure of the two Americas, I have shown that their two meridian chains are separated by 30° of longitude; the union between them being effected by two parallel, more modern, south-easterly, chains, inclosing the Gulf of Mexico and the Caribbean Sea. A somewhat similar connecting chain occurs in the eastern hemisphere, linking the meridian chains of Europasia with that of Australia in the southern hemisphere.

Asiatic Connecting Chain.

A meridian range of mountains starts from the point where the Himalayas terminate somewhat abruptly in the east. This range runs south to Singapore, a distance of 2000 miles, forming the axis of Burmah, Siam, and the Malay peninsula. The axis of elevation then turns to the eastward, forming the Eastern Archipelago, including Sumatra, Java, Borneo, the Sunda Isles, and Papua (New Guinea). Here the chain again turns south, and seems to become merged in the meridian range of East Australia.

Like the corresponding connecting range in America, this connecting chain is volcanic, and more modern than the meridian chains. The volcanic axis attains a mean height of 11,000 feet in Sumatra, 10,000 feet in Java, and 6000 feet in the other islands. It extends in longitude through 50°.

Humboldt estimates the maximum mean height of Europe at 671 feet, and that of Asia at 1132 feet.*

---

* The maximum mean height of all the continents may be found from the formula—

$$AH = ah + a'h' + \&c.,$$

where

A = total area,
H = mean total height of land,
a, a', &c., = area of each continent,
h, h', &c., = mean height of each continent.

The data necessary for the calculations are—

	Area.	Maximum mean height.
Europe, ...	3·4 millions of square miles.	671 feet.
Asia, ...	17·6 ,, ,, ,,	1132 ,,
Africa, ...	11·3 ,, ,, ,,	900 ,,
North America, . .	7·2 ,, ,, ,,	748 ,,
South America, . .	6·8 ,, ,, ,,	1151 ,,
Australia, . . .	3·0 ,, ,, ,,	500 ,,

From these figures we obtain—

$$H = \frac{ah + a'h' + \&c.}{A}$$

$$= \frac{470870}{493} = 955 \text{ feet.}$$

That is to say, the mean height of the land is certainly less than 1000 feet: while the mean depth of the ocean is certainly over 10,000 feet.

If the sea were dried up and the bottom exposed, two things would strike us with surprise—

1. *The flatness of the sea bottom as compared with the land surface.*
2. *The abrupt, precipitous line of demarcation separating the sea bottom from the land surface.*

The first of these facts may be partly explained by the absence of degrading forces at the sea bottom, such as rainfall, surface waves, and other agencies that continually modify and alter the land surface; and also by the ocean currents carrying particles mechanically suspended, which gradually fill up the sea bottom.

The most abrupt change of level on the land surface, that we are acquainted with, is in the southern face of the Himalayas, in Bhotan, where it reaches 10,000 feet in 10 miles of horizontal distance, forming in fact a grand mural precipice. This sudden change of level, so rare on the land surface, or on the sea bottom, is the almost universal characteristic of the passage from shallow into deep soundings near the sea coast. The following examples will suffice—

(*a*). At the entrance of the British Channel, we pass from 600 feet to 12,000 feet within a horizontal distance of 10 miles.

(*b*). Within 80 miles of the coast at Valparaiso the sea acquires a depth of 13,350 feet.

(*c*). At 50 miles to the south-east of Owhyhee (Sandwich Islands), the sea is 17,250 feet deep. There exist on this island two volcanoes, nearly 14,000 feet in height, viz.—Mauna Kea and Mauna Roa; so that at this point of the surface of the earth we can draw two radii, only 50 miles apart, and yet differing in length by 31,000 feet.

(*d*). I have already shown, by the Arica sea-wave, that there is a mean depth of 11,450 feet,* close along the west coast of both Americas.

(*e*). The island of Tristan da Cunha, in the South Atlantic Ocean, rises abruptly from the bottom of an ocean, 12,150 feet in depth. If the sea bottom were exposed, such an island would look like a gigantic spire, raised by artificial means, like the tower of Babel.

(*f*). Many of the islands in the Red Sea, not more than a few acres in extent, rise perpendicularly out of the deep water, and would look like gigantic columns, if the sea were dried up.

It follows from this, that our coast lines indicate lines of fault, or dislocation in the solid parts of the earth's surface, which occurred at the time of the formation of the oceans and continents.†

The accompanying map (Fig. 7) shows the form of the bottom of the Atlantic Ocean.

The unshaded portions are less than one geographical mile in depth, under 6000 feet. The shaded portions are more than one mile and less than two miles in depth, between 6000 and 12,000 feet. The black portions are more than 12,000 feet in depth. This map shows:—

---

* The mean of the depths determined from the San Diego and Fort Point observations, p. 31.

† Faults of similar amounts are known to geologists. Thus, between Aran Mowddwy and Careg Aderyn, in North Wales, the strata are displaced 10,500 feet. The great fault crossing Scotland from near Dunbar to the Ayrshire coast, and which separates the Silurians of the south of Scotland from the Old Red Sandstone and Carboniferous beds of the north, has, in some places, a throw of 15,000 feet. In front of the Chilowee Mountain, North America, there is a vertical displacement of the strata of more than 10,000 feet in amount.

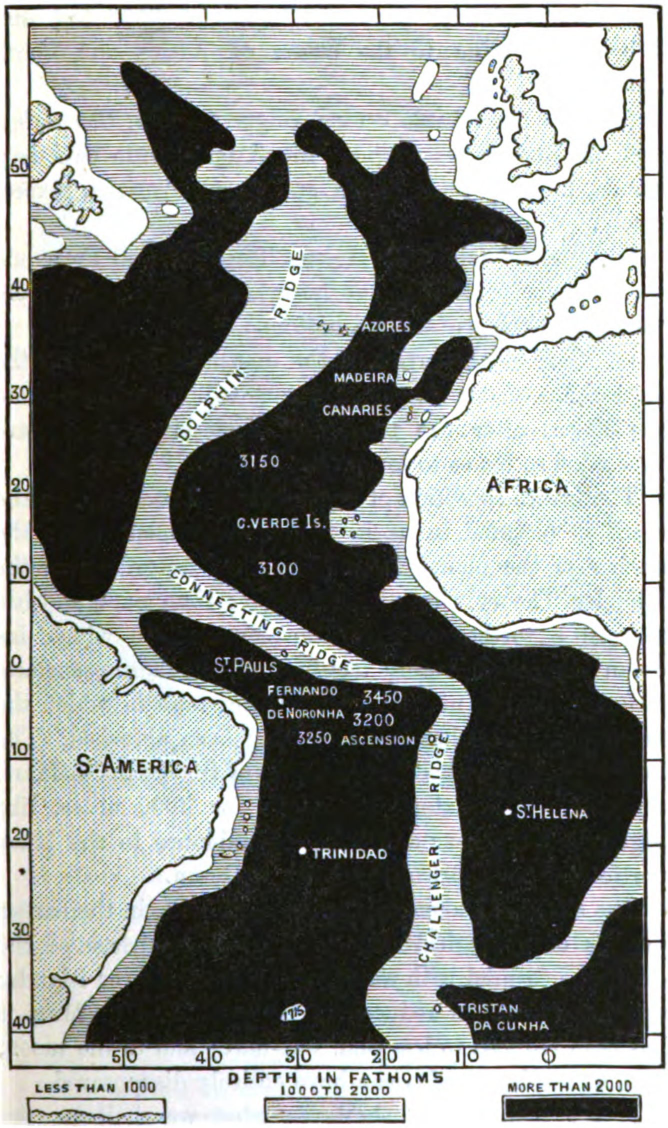
AZORES
DOLPHIN RIDGE
MADEIRA
CANARIES
3150
AFRICA
C. VERDE Is.
3100
CONNECTING RIDGE
ST. PAULS
FERNANDO DE NORONHA
3450
3200
3250
ASCENSION
S. AMERICA
CHALLENGER RIDGE
ST. HELENA
TRINIDAD
TRISTAN DA CUNHA
50
40
30
20
10
0
DEPTH IN FATHOMS
LESS THAN 1000
1000 TO 2000
MORE THAN 2000

Fig. 7.

(*a*). How closely the contour lines of 6000 feet and 12,000 feet cling to the coasts of Africa and South America.

(*b*). The remarkable central ridge (*Dolphin, Connecting,* and *Challenger*) that divides the Atlantic into two deep canals, keeping near Africa and South America respectively.

(*c*). The Islands of St. Helena, Trinidad, and Fernando de Noronha (especially the latter), rising abruptly from the deepest parts of the sea bottom.

(*d*). The black portion of the diagram shows what the appearance of our terrestrial oceans will be, as seen from the moon, after the process of desiccation shall have proceeded so far as to lower the sea level 12,000 feet.

The future condition of continents and oceans upon the earth is pictured to us in their arrangement upon the surface of the planet Mars (Fig. 8). According to the Nebular Theory, this planet is older than ours, and has reached a further stage of development, in which his ocean surface is barely one-half of the entire surface, although he has not yet attained the stage in which the moon now is, all her oceans having been absorbed. The long "bottled-necked" appearance of the oceans of Mars, some of which extend in length for 3000 miles, like gigantic rivers, bear a striking resemblance to the black portions of our chart of the Atlantic Ocean.

The study of Palæontology shows us that, in the earlier periods of geological history, the whole surface of the earth was covered with water, with a few scattered islands; this has now been reduced to three-fourths; in Mars it has been reduced to less than one-half; and in the moon, both atmosphere and ocean have entirely disappeared.

If the planet Mars shows us what we shall be, the planet Venus shows us what we have been—Venus contains mountain ridges upwards of 25 miles in height, in comparison with which our giant Himalayas would appear like pygmies. This is readily explained—for mountain ridges are produced by the tangential pressure of the

Fig. 8.*

outer layers of a planet contracting in consequence of the radiation of its heat. The inner or hotter portions contract faster than the outer portions, from which, therefore, the support of the inner portions is partially withdrawn†,

* Mars, in opposition, at midnight 27th May, 1873; after Proctor.

† If the support of the inner layers were *wholly* withdrawn, the mutual tangential pressures upon a square mile of surface rock would be equal to

and the outer shell is crushed together by overwhelming tangential thrusts, which corrugate and wrinkle its surface into mountain chains and deep-sea-valleys. This process of mountain and valley manufacture goes on in every planet, as long as it is losing heat by radiation; and it goes on the more vigorously in proportion as the loss of heat is greater. Therefore Venus has loftier and grander mountain chains than the earth; and the earth herself, in her younger days (as is testified by the gigantic foldings and wrinklings of the Palæozoic rocks in comparison with those of the Neozoic rocks), indulged in the pastime of making mountains and valleys, as grand as those now existing in the planet Venus.

The continents of the globe may be regarded as flat-topped table-lands raised slightly above the sea level, with precipitous cliffs all round, exceeding 12,000 feet in depth; these cliffs corresponding in all probability to ancient lines of faults, of different geological ages.

If the earth were stripped of its oceans, we should at once perceive the true amount of *wrinkling* of its surface produced by geological causes. If we call the zero plane the original surface of the globe before it became wrinkled at all, we can easily see that it lies far below the sea level.

---

the weight of a column of granite one square mile in section, and nearly 2000 miles high. For, we have—

$$P = \frac{2T}{r};$$

where P is the vertical pressure upon a square mile of surface, T is the tangential pressure, and r is the radius of the spherical shell. If the shell were *wholly* unsupported, the tangential pressure above described would be nearly 500 times as great as would be required to crush granite or porphyry, so that, even if the inner portions support the weight of nearly the whole outer shell, the latter must be crushed and crumpled by the tangential thrusts remaining unbalanced.

The zero plane is the surface of the ellipsoid similar to the sea surface, and containing the same volume as the total solid matter of the globe. It is thus found: assuming the mean height of the continents above the sea level at about 1000 feet, and the mean depth of the ocean at about 10,000 feet, we have, in miles,

$$x = \frac{2{\cdot}083\,L}{W + L},$$

where x is the height of the zero plane above the present mean sea bottom, and L, W, are the areas of land and water:

L = 52 millions of square miles.
W = 145 ,, ,, ,,

Substituting in the equation, we find

$$x = 0{\cdot}550 \text{ mile.}$$

The zero plane, therefore, or original surface of the solid earth before it became wrinkled by geological forces, lay at a depth of more than 7000 feet below the present sea level.

The continents of the globe, therefore, represent enormous masses of surface rock, elevated by subterranean force through a height of 8000 feet, and not merely lifted through the small amount that represents their elevation above the plane of the sea level.*

The mountain chains are the axes of elevation along which the continents were raised, and differ from each other considerably in geological age.

The most modern of the mountain chains is the great east and west chain of Europasia, which produced the

* The geological manufacture of continents must have displaced the axis of figure by small amounts—not exceeding 100 miles in any case.

continent. The Nummulitic limestone* (which often contains upwards of fifty species of Nummulite) occupies a very definite geological horizon, that of the Middle Eocene. One or two species only of Nummulites survive the Eocene period and live on into the Lower Miocene, and it is doubtful if any species occur in the Lower Eocene.

The Nummulitic formation is found of great thickness, and at considerable height, in the Pyrenees, the Alps, Carpathians, Caucasus, and Himalayas—

Dent de Midi (Pyrenees), . . .	10,531 feet,
Diablerets (Alps), ...	10,670 „
Western Thibet, ...	16,500 „

it covers large parts of the Pyrenean and Mediterranean basins, being widely developed in Algeria, Morocco, and Egypt (whose pyramids were in part made of Nummulitic limestone). It occurs in the Apennines and Carpathians, Asia Minor, Persia, Afghanistan, and Bengal, up to the Chinese frontier. This remarkable formation is also found in Java, Luzon, and Japan.

The Nummulitic limestone formation extends through 98° of longitude, and is found in latitudes ranging from 15° N. to 55° N.

The Nummulites of the pyramids attracted the notice of Strabo, who had been familiar with them previously, as a native of Amasis, in Pontus, Asia Minor. He says†—

"We do not think it fit to pass over in silence a singular thing which we saw at the Pyramids, viz., the heaps of chipped stone that lie in front of these monu-

* So called, because it is composed of the round, flat, coin-like (*nummus*) disks of the Nummulites, a fossil form of Rhizopod, which secreted a calcareous skeleton.

† Strabo, *Geography*, lib. xvii., p. 808; Paris, 1620.

ments. There are among these fragments some that in form and size resemble beans, one would say, with the skin half removed. These are said to be the petrified remains of the food of the workmen; but this is very improbable, for in our own country there is an oblong hill in the middle of the plain which is full of bean-like pebbles, made of a white porous limestone."

No modern geologist could write a better description of the appearance of Nummulite limestone.

As the Nummulitic is a marine formation, it is plain that the elevation of the great east and west axis of Europasia is geologically modern; and it has been shown that England was inhabited by herbivorous pachyderms, by insectivorous bats, and by opossums, previous to the elevation of the east and west chain, which converted large regions of Central Asia, Central and Southern Europe, and North Africa, from sea into dry land.*

Volcanoes.—The connexion between mountain chains and volcanoes has been long recognised; and some authors, as Mr. Robert Mallet, assign to both a common origin, viz., the development of heat and mechanical displacement, consequent on the contraction of the globe due to secular cooling. Two characteristics of the distribution of volcanoes attract at once our attention—

1. *Their generally linear arrangement.*
2. *Their frequent connexion with coast lines.*

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* I have shown (*Proc. R. S.*, No. 179, 1877) that the elevation of Europasia displaced the axis of figure in the earth through 69 miles—giving rise to a complicated series of *wabbles* in the earth's axis, which have gradually died out in consequence of the friction of the ocean against the land, and are now no longer visible to astronomers. I have also succeeded in proving, that if Europasia were produced *per saltum*, it would require upwards of 600,000 years for the wabble to disappear.

Volcanic Chains of the Pacific Ocean.—If we examine the Pacific Ocean, we shall find a line of volcanoes (recent or extinct) following the eastern margin of the ocean, along the Andes, Central America, and the Rocky Mountains. From the peninsula of Aliaska the volcanic axis passes into Kamtschatka by the Aleutian Islands. From Kamtschatka, a chain of volcanic islands runs south-west, parallel to the coast of Asia, through Japan and the Philippine Islands to the south-east of Borneo. This volcanic chain includes, between itself and the coast of Asia, the following mediterranean seas—Sea of Okhotsk, Sea of Japan, Yellow Sea, China Sea.

Another great volcanic axis meets the Japanese axis at Sumbawa, and seems to cut it short. This second great axis contains Sumatra, Java, Lomboc, Sumbawa, and extends eastward to the island of New Guinea.

The whole coast line of the Pacific Ocean coincides, therefore, on every side, with a line of volcanic activity.

Humboldt gives the following summary of the American volcanoes:—

1. *Group of Chili.*—In number twenty-four, of which thirteen are active, including, from south to north:—

Yntales, . .	Lat. 43° 29′.	Height,	8,030 feet.
Corcovado, .	„ 43 12.	„	7,509 „
Minchinmadom,	„ 42 48.	„	7,993 „
Osorno, . .	„ 41 9.	„	7,443 „
Antuco, . .	„ 37 7.	„	8,920 „
Chillan, . .	„ 36 2.	„	13,100 „
Maypu, . .	„ 34 17.	„	17,662 „
Tupungato, .	„ 33 22.	„	22,016 „
Aconcagua, .	„ 32 39.	„	23,910 „

2. *Group of Peru and Bolivia.*—In number fourteen, of which three are active, including, from south to north :—

Guatalieri,	. Lat. 18° 25.	Height, 21,962	feet.
Parinacote, .	„ 18 12.	„ 22,029	„
Pomarape, .	„ 18 8.	„ 21,699	„
Sahama, . .	„ 18 7.	„ 22,354	„
Tacora, . .	„ 17 45.	„ 19,738	„
Pichu-Pichu, .	„ 16 25.	„ 9,673	„
Arequipa, . .	„ 16 20.	„ 18,879	„
Chacani, . .	„ 16 11.	„ 19,601	„

3. *Group of New Granada and Quito.* — In number eighteen, of which ten are active, including :—

Cotopaxi, ...	18,881	feet.
Tolima, ...	18,143	„
Sangay, ...	17,128	„
Puracé, ...	17,010	„
Tungurahna, ...	16,494	„
Rucu-Pichincha, ...	15,926	„
Cumbal, ...	15,621	„
Pasto, ...	13,453	„
Tuqueres, ...	12,824	„

4. *Group of Central America.*—In number twenty-nine, of which eighteen are active, including the following :—

Turrialva, ...	11,000	feet.
Irasu, ...	11,100	„
El Reventado, ...	9,500	„
Barba, ...	8,419	„
Votos, ...	7,513	„
Momotombo, ...	7,034	„
Volcan de Fuego, ...	14,665	„
Volcan de Agua, ...	14,903	„

5. *Group of Mexico.*—In number six, of which four are active, including the following :—

Orizaba, ...	17,783	feet.
Popocatapetl, ...	17,729	„
Toluca, ...	15,168	„
Jorullo, ...	4,266	„
Colima, ...	—	
Tuxtla, ...	—	

6. *Rocky Mountain Group.* — Most of the Rocky Mountain volcanoes are extinct, and include the following, from south to north:

Mount Taylor, ...		12,256	feet.
San Francisco Mountain, .		16,000	„
Fremont's Peak, ...		13,568	„
Mount Pitt, . . .	(42° 30′),	9,548	„
Mount Hood, . .	(45 10),	15,500	„
Mount St. Helen's,	(46 12),	15,000	„
* Mount Rainier, .	(46 48),	12,330	„
Mount Brown, . .	(52 15),	16,750	„
Mount Fairweather, . . .		14,710	„
Mount Elias, . .	(60 17),	17,854	„

At Behring's Straits commences the chain of volcanic islands which bounds the western part of the Pacific Ocean. It contains the following:

7. *Aleutian Islands' Chain.*—The peninsula of Aliaska is prolonged into the chain of the Fox and Aleutian Islands, forming a connecting link between North America and Asia, extending like a bar for upwards of 1000 miles

* Active.

in length across the entrance of Behring's Straits, from Aliaska peninsula to Kamtschatka peninsula. This chain of volcanic islands contains upwards of thirty-four active volcanoes—the highest of which are

Unimak, ...	8,076 feet.
Matuschkin, ...	5,474 „

8. *Kamtschatka and Japan Chain.*—This may be called the Eastern Asiatic volcanic chain, and it extends upwards of 3000 miles, including Kamtschatka, the Kurile Islands, and the Islands of Japan, and terminates in the Island of Formosa—running S.W. and parallel to the east coast of Asia. The most important of the Kamtschatkan* volcanoes, reckoned from north to south, are:—

Schiwelutsch, (α) . . .	(56 40),	10,544 „
„ „ (β) . . .	(56 39),	8,793 „
Kliutschewskaja Sopka,	(56° 4′),	15,763 feet.
Uschinskaja Sopka, . .	(56 0),	11,723 „
Tolbatschinskaja Sopka,	(55 51),	8,313 „
Kronotskaja, ...	(54 8),	10,609 „
Jupanowa Sopka, . . .	(53 32),	9,055 „
Koriatskaja, ...	(53 19),	11,210 „
Awatschinskaja, . . .	(53 17),	8,910 „
Wiljutschinsker, . . .	(52 52),	7,373 „
Poworotnaja Sopka, . .	(52 22),	7,930 „
Opalinskaja, ...	(51 21),	12,000 „

* The relative degrees of concentration of volcanic forces round the basin of the Pacific may be thus seen:—

(*a*).	In Chili,	there are	24 volcanoes	in 960 G.M.	= 1 in 40 G.M.
(*b*).	„ Peru and Bolivia	„	14 „	„ 420 „	= 1 „ 30 „
(*c*).	„ Central America,	„	29 „	„ 680 „	= 1 „ 23 „
(*d*).	„ Kamtschatka,	„	14 „	„ 420 „	= 1 „ 30 „

The Kurile Islands, connecting Kamtschatka with Japan, contain ten volcanoes in 720 G.M., of which the most important are :—

Alaid, ...	13,500 feet.
Mataua, ...	4,193 „

The volcanoes of the Japanese and Corean Islands are comparatively unknown. The historical books of Japan mention only six active volcanoes, two in the Island of Niphon, and four in the Island of Kiu-siu; these are, from north to south, as follows :—

Asama jama,	.	earliest record,	A.D. 864.
Fusi jama,	. . .	12,441 feet,	A.D. 799.
Vunzen,	(32° 44′),	4,110 „	
Aso jama,	(32 45).		
Kirisima,	(31 45).		
Mitake,	(31 33).		

Modern voyagers have added two other active volcanoes in islands near Japan, viz. :—

Ivôgasima, . .	(30° 43′),	2,364 feet.
Ohosima, . . .	(34 42),	—

In the Island of Jesso, to the north of Niphon, Siebold reckoned seventeen extinct volcanoes.

The Formosa, Philippine, Sunda, and Molucca chain of volcanic islands completes the primary volcanic chain of the Pacific Ocean, and contains a very large number of extinct volcanoes, although the number of active volcanoes is small.

9. *Volcanic Chain of the Sunda Isles.*—This important east and west line of volcanic force extends from

Sumatra to New Guinea, cutting off the Asiatic coast chain at right angles, and reminds us of the manner in which the east and west line of the Mexican volcanoes cuts off the chain of the older Rocky Mountain volcanic system.

Commencing on the west with Sumatra, we have nineteen volcanoes, of which six are active, viz. :—

Gunung Indrapura, . . .	12,256 feet.
Gunung Pasaman (Ophir), .	9,602 „
Gunung Salasi, ...	—
Gunung Merapi, ...	9,751 „
Gunung Ipu, ...	—
Gunung Dempo, ...	9,940 „

There are in

Java, ...	28 active volcanoes.
Celebes, ...	11 „ „
Flores, ...	6 „ „

The most important of the Javan volcanoes are :—

Gunung Semeru, ...	12,233 feet.
Gunung Ardjuno, ...	11,031 „
Gunung Slamat, ...	11,116 „
Gunung Sumbing, ...	11,029 „
Gunung Lawu, ...	10,726 „

In addition to these, there are seven volcanoes whose heights lie between 9000 feet and 10,000 feet. The volcano, Gunung Tengger, which is of the second class (being only 8704 feet in height), is remarkable for having the largest known crater in the world. It has a mean diameter of 21,315 feet, and exceeds in area the famous crater of Kilauea, in Owhyhee.

The other important volcanoes of the Sunda Islands are:

Rindjani (Lomboc), . . .	12,363 feet.
Tomboro (Sumbawa),. . .	5,862 „
Ternate, ...	5,756 „

It is stated by Junghuhn, that in the circle of islands which surrounds the almost continental Borneo, there have been actually counted

109 fire-emitting volcanoes,
10 mud volcanoes.

10. *Australian Volcanic Island Chain.*—This volcanic chain extends eastward, in continuation of the Sunda chain, through New Guinea, and then sweeps to the south-eastward and southward, through the Solomon Isles, and the New Hebrides, to New Zealand, where it terminates. It keeps parallel to the eastern coast of Australia, just as the Kamtschatka-Japanese chain runs parallel to the east coast of Asia. The change of direction of this volcanic chain, from eastward to southward, reminds us of the similar change in the Mexican volcanic axis, in passing through Cuba into the West Indian Islands.

There are two volcanoes in New Guinea, and three in New Britain; and in the Solomon group, and in the Santa Cruz group, there are several more. The entire chain terminates in the large islands of New Zealand, which abound in examples of volcanoes, mostly extinct, including:—

*Tongariro, ...	6,198 feet.
Ruapahu,.	9,006 „
Mount Edgecumbe, . . .	9,630 „
Mount Egmont, ...	8,840 „
*White Island, ...	—

* Active.

The line of volcanic forces, which I have just described, starting from Tierra del Fuego, through the Andes, Central America, Rocky Mountains, Aleutian Islands, Kamtschatka, Japan, Philippines, Sunda, New Guinea, and the Eastern Australian Islands, and terminating in New Zealand, is 24,000 miles in length, or equal to the circumference of the whole globe. It surrounds, almost completely, the Pacific Ocean, which is the largest mass of water on the globe—having an area nearly one-sixth greater than that of all the land surfaces put together, and an equatorial axis of 12,000 miles in length (from Quito to Sumatra being exactly half way round the earth). The total number of active volcanoes existing on the borders of the Pacific is 172, being considerably more than half the entire number of active volcanoes on the earth, viz., 225. The large basin of the Pacific itself contains only 26 active volcanoes, scattered here and there. The island of Java, alone, contains a greater number (28) of active volcanoes than the whole Pacific basin.

The most remarkable of the isolated volcanoes of the Pacific basin, and perhaps the most interesting volcanoes on the globe, are those of the Sandwich Islands. The most important of these are situated in the island of Owhyhee, viz.:—

Mauna Loa, ...	13,758 feet.
Mauna Kea, ...	13,951 „
Kilauea, ...	3,870 „
Mauna Hualalai, ...	10,000 „

The summit crater of Mauna Loa is 11,000 feet in its greatest diameter, and 8000 feet in its least diameter, and from it lava streams have frequently flowed for thirty miles, extending to the foot of the mountain. The appearance of the crater of Mauna Loa, in its quieter moods, is well described by an eye-witness.*

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* "We were then, as we knew, close to the edge of the crater, but the faint smoke wreath had disappeared, and there was nothing but the westering sun hanging like a ball over the black horizon of the desolate summit. We rode as far as a deep fissure filled with frozen snow, with a ledge beyond, threw ourselves from our mules, jumped the fissure, and more than 800 feet below yawned the inaccessible blackness and horror of the crater of Mokuaweoweo, six miles in circumference, and 11,000 feet long by 8,000 wide. The mystery was solved, for at one end of the crater, in a deep gorge of its own, above the level of the rest of the area, there was the lonely fire, the reflexion of which, for six weeks, has been seen for 100 miles.

"Nearly opposite to us, a thing of beauty, a perfect fountain of pure yellow fire, unlike the gory gleam of Kilauea, was regularly playing in several united but independent jets, throwing up its glorious incandescence, to a height, as we afterwards ascertained, of from 150 to 300 feet, and attaining at one time 600! You cannot imagine such a beautiful sight. The sunset gold was not purer than the living fire. The distance which we were from it divested it of the inevitable horrors which surround it. It was all beauty. For the last two miles of the ascent, we had heard a distant vibrating roar: there, at the crater's edge, it was a glorious sound, the roar of an ocean at dispeace, mingled with the hollow murmur of surf echoing in sea caves, booming on, rising and falling, like the thunder music of windward Hawaii.

"We sat on the ledge outside the fissure for some time, and Mr. Green actually proposed to pitch the tent there, but I dissuaded him, on the ground that an earthquake might send the whole thing tumbling into the crater; nor was this a whimsical objection, for during the night there were two such falls, and after breakfast, another quite near us.

"We had travelled for two days under a strong impression that the fires had died out, so you can imagine the sort of stupor of satisfaction with which we feasted on the glorious certainty. Yes, it was glorious, that far-off fire-fountain, and the lurid cracks in the slow-moving, black-crusted flood, which passed calmly down from the higher level to the grand area of the crater.

"This area, over two miles long, and a mile and a half wide, with precipitous sides 800 feet deep, and a broad second shelf about 300 feet

The crater of Kilauea forms a deep pit on the east slope of Mauna Loa, 16,000 feet in its greatest diameter, and 7460 feet in its least diameter.

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below the one we occupied, at that time appeared a dark grey, tolerably level lake, with great black blotches, and yellow and white stains, the whole much fissured. No steam or smoke proceeded from any part of the level surface, and it had the unnaturally dead look which follows the action of fire. A ledge, or false beach, which must mark a once higher level of the lava, skirts the lake, at an elevation of thirty feet probably, and this fringed the area with various signs of present volcanic action, steaming sulphur banks, and heavy jets of smoke. The other side, above the crater, has a ridgy broken look, giving the false impression of a mountainous region beyond. At this time the luminous fountain, and the red cracks in the river of lava which proceeded from it, were the only fires visible in the great area of blackness. In former days people have descended to the floor of the crater, but owing to the breaking away of the accessible part of the precipice, a descent now is not feasible, though I doubt not that a man might even now get down, if he went up with suitable tackle, and sufficient assistance.

"The one disappointment was that this extraordinary fire-fountain was not only 800 feet below us, but nearly three-quarters of a mile away from us, and that it was impossible to get any nearer to it. Those who have made the ascent before have found themselves obliged either to camp on the very spot we occupied, or a little below it.

"The natives pitched the tent as near to the crater as was safe, with one pole in a crack, and the other in the great fissure, which was filled to within three feet of the top with snow and ice. As the opening of the tent was on the crater side, we could not get in or out without going down in this *crevasse*. The tent walls were held down with stones to make it as snug as possible, but *snug* is a word of the lower earth, and has no meaning on that frozen mountain top. The natural floor was of rough slabs of lava, laid partly edgewise, so that a newly macadamised road would have been as soft a bed. The natives spread the horse blankets over it, and I arranged the camping blankets, made my own part of the tent as comfortable as possible by putting my inverted saddle down for a pillow, put on my best reserve of warm clothing, took the food out of the saddle bags, and then felt how impossible it was to exert myself in the rarified air, or even to upbraid Mr. Green for having forgotten the tea, of which I had reminded him as often as was consistent with politeness!

The steaming, bubbling, and foaming mass which under ordinary circumstances forms the true lava-pool of Kilauea, does not, however, fill the whole of this cavity, but a

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"This discovery was not made till after we had boiled the kettle, and my dismay was softened by remembering that as water boils up there at 187°, our tea would have been worthless. In spite of my objection to stimulants, and in defiance of the law against giving liquor to natives, I made a great tin of brandy toddy, of which all partook, along with tinned salmon and dough-nuts. Then the men piled faggots on the fire and began their everlasting chatter, and Mr. Green and I, huddled up in blankets, sat on the outer ledge in solemn silence, to devote ourselves to the volcano.

"The sun was just setting: the tooth-like peaks of Mauna Kea, cold and snow-slashed, which were blushing red, the next minute turned ghastly against a chilly sky, and with the disappearance of the sun it became severely cold; yet we were able to remain there till 9·30, the first people to whom such a thing has been possible, so supremely favoured were we by the absence of wind.

"When the sun had set, and the brief red glow of the tropics had vanished, a new world came into being, and wonder after wonder flashed forth from the previously lifeless crater. Everywhere through its vast expanse appeared glints of fire—fires bright and steady, burning in rows like blast furnaces; fires lone and isolated, unwinking like planets, or twinkling like stars; rows of little fires marking the margin of the lowest level of the crater; fire molten in deep *crevasses;* fire in wavy lines; fire, calm, stationary, and restful: an incandescent lake two miles in length beneath a deceptive crust of darkness, and whose depth one dare not fathom even in thought. Broad in the glare, giving light enough to read by at a distance of three-quarters of a mile, making the moon look as blue as an ordinary English sky, its golden gleam changing to a vivid rose colour, lighting up the whole of the vast precipices of that part of the crater with a rosy red, bringing out every detail here, throwing cliffs and heights into huge black masses there, rising, falling, never intermitting, leaping into lofty jets with glorious shapes like wheat-sheaves, coruscating, reddening, the most glorious thing beneath the moon was the fire-fountain of Mokuaweoweo.

"By day the cooled crust of the lake had looked black and even sooty, with a fountain of molten gold playing upwards from it; by night it was all incandescent, with black blotches of cooled scum upon it, which were perpetually being devoured. The centre of the lake was at white heat, and space whose long diameter is 14,000 feet, and its breadth 5000 feet. This seems to be the high level of the sea of molten lava, which fluctuates in height, sometimes retiring

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waves of white hot lava appeared to be wallowing there as in a whirlpool, and from this centre the fountain rose, solid at its base, which is estimated at 150 feet in diameter, but thinning and frittering as it rose high into the air, and falling from the great altitude to which it attained, in fiery spray, which made a very distinct clatter on the fiery surface below. When one jet was about half high, another rose so as to keep up the action without intermission; and in the lower part of the fountain two subsidiary curved jets of great volume continually crossed each other. So, 'alone in its glory,' perennial, self-born, springing up in sparkling light, the fire-fountain played on as the hours went by.

"From the nearer margin of this incandescent lake there was a mighty but deliberate overflow, a 'silent tide' of fire, passing to the lower level, glowing under and amidst its crust, with the brightness of metal passing from a furnace. In the bank of partially cooled and crusted lava which appears to support the lake, there were rifts showing the molten lava within. In one place heavy white vapour blew off in powerful jets from the edge of the lake, and elsewhere there were frequent jets and ebullitions of the same, but there was not a trace of vapour over the burning lake itself. The crusted large area, with its blowing cones, blotches and rifts of fire, was nearly all visible, and from the thickness and quietness of the crust it was obvious that the ocean of lava below was comparatively at rest, but a dark precipice concealed a part of the glowing and highly agitated lake, adding another mystery to its sublimity.

"It is probable that the whole interior of this huge dome is fluid, for the eruptions from this summit crater do not proceed from its filling up and running over, but from the mountain sides being unable to bear the enormous pressure; when they give way, high or low, and bursting, allow the fiery contents to escape. So, in 1855, the mountain side split open, and the lava gushed forth for thirteen months in a stream which ran for 60 miles, and flooded Hawaii for 300 square miles.*

"From the camping ground, immense cracks parallel with the crater extend for some distance, and the whole of the compact grey stone of the summit is much fissured. These cracks, like the one by which our tent was pitched, contain water resting on ice. It shows the extreme difference

* Since white men have inhabited the islands, there have been ten recorded eruptions from the craters of Mauna Loa, and one from Hualalai.

into a succession of deeper pits, each of less area than the higher ones. The lava in Kilauea is always a molten sheet more or less completely filling the funnel-shaped aperture by which the surface communicates with

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of climate on the two sides of Hawaii, that while vegetation straggles up to a height of 10,000 feet on the windward side in a few miserable blasted forms, it absolutely ceases at a height of 7000 feet on the leeward.

"It was too cold to sit up all night; so by the "fire light" I wrote the enclosed note to you with fingers nearly freezing on the pen, and climbed into the tent.

"It is possible that tent life in the East, or in the Rocky Mountains, with beds, tables, travelling knick-knacks of all descriptions, and servants who study their master's whims, may be very charming; but my experience of it having been of the make-shift and non-luxurious kind is not delectable. A wooden saddle, without stuffing, made a very fair pillow; but the ridges of the lava were severe. I could not spare enough blankets to soften them, and one particularly intractable point persisted in making itself felt. I crowded on everything attainable, two pairs of gloves, with Mr. Gilman's socks over them, and a thick plaid muffled up my face. Mr. Green and the natives, buried in blankets, occupied the other part of the tent. The phrase, 'sleeping on the brink of a volcano,' was literally true, for I fell asleep, and fear I might have been prosaic enough to sleep all night, had it not been for fleas which had come up in the camping blankets. When I woke, it was light enough to see that the three muffled figures were all asleep, instead of spending the night in shiverings and vertigo, as it appears others have done. Doubtless the bathing of our heads several times with snow and ice-water had been beneficial.

"Circumstances were singular. It was a strange thing to sleep on a lava-bed at a height of nearly 14,000 feet, far away from the nearest dwelling, 'in a region,' as Mr. Jarves says, 'rarely visited by man,' hearing all the time the roar, clash, and thunder of the mightiest volcano in the world. It seemed all a wild dream, as that majestic sound moved on. There were two loud reports, followed by a prolonged crash, occasioned by parts of the crater walls giving way; vibrating rumblings, as if of earth-quakes; and then a louder surging of the fiery ocean, and a series of most imposing detonations. Creeping over the sleeping forms, which never stirred even though I had to kneel upon one of the natives while I untied the flap of the tent, I crept cautiously into the *crevasse* in which the snow-water was then hard frozen, and out upon the projecting ledge. The four hours in which we had previously watched the volcano had passed like one; but the

the interior of the earth. It has never been known to overflow the crater, and this is the more remarkable from the fact that Kilauea rests on the slope of Mauna Roa, at an altitude of about 4000 feet, while

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lonely hours which followed might have been two minutes or a year, for time was obliterated.

"Coldly the Pole-star shivered above the frozen summit, and a blue moon, nearly full, withdrew her faded light into infinite space. The Southern Cross had set. Two peaks below the Pole-star, sharply defined against the sky, were the only signs of any other world than the world of fire and mystery around. It was light—broadly, vividly light; the sun himself, one would have thought, might look pale beside it. But such a light! The silver index of my thermometer, which had fallen to 23° Fahrenheit, was ruby red; that of the aneroid, which gave the height at 13,803 feet (an error of 43 feet in excess), was the same. The white duck of the tent was rosy, and all the crater walls and the dull-grey ridges which lie around were a vivid rose-red.

"All Hawaii was sleeping. Our Hilo friends looked out the last thing; saw the glare, and probably wondered how we were 'getting on,' high up among the stars. Mine were the only mortal eyes which saw what is perhaps the grandest spectacle on earth. Once or twice I felt so overwhelmed by the very sublimity of the loneliness, that I turned to the six animals, which stood shivering in the north wind, without any consciousness than that of cold, hunger, and thirst. It was some relief even to pity them, for pity was at least a human feeling, and a momentary rest from the thrill of the new sensations inspired by the circumstances. The moon herself looked a wan unfamiliar thing—not the same moon which floods the palm and mango groves of Hilo with light and tenderness. And those palm and mango groves, and lighted homes, and seas, and ships, and cities, and faces of friends, and all familiar things, and the day before, and the years before, were as things in dreams, coming up out of a vanished past. And would there ever be another day, and would the earth ever be young and green again, and would men buy and sell and strive for gold, and should I ever with a human voice tell living human beings of the things of this midnight? How far it was from all the world, uplifted above love, hate, and storms of passion, and war, and wreck of thrones, and dissonant clash of human thought, serene in the eternal solitudes!

"Things had changed, as they change hourly in craters. The previous loud detonations were probably connected with the evolutions of some 'blowing cones,' which were now very fierce, and throwing up lava at the comparatively dead end of the crater. Lone stars of fire broke out

Mauna Roa has an altitude of nearly 14,000 feet, so that when both craters are in a state of activity together,* if there were any communication between their respective reservoirs of molten lava, Kilauea would exhibit the phenomenon of a lava fountain, spouting many thousands of feet into the air.

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frequently through the blackened crust. The molten river, flowing from the incandescent lake, had advanced and broadened considerably. That lake itself, whose diameter has been estimated at 800 feet, was rose-red and self-illuminated, and the increased noise was owing to the increased force of the fire-fountain, which was playing regularly at a height of 300 feet, with the cross-fountains, like wheat-sheaves, at its lower part. These cross-fountains were the colour of a mixture of blood and fire, and the lower part of the perpendicular jets was the same; but as they rose and thinned, this colour passed into a vivid rose-red, and the spray and splashes were as rubies and flame mingled. For ever falling in fiery masses and fiery foam: accompanied by a thunder-music of its own: companioned only by the solemn stars: exhibiting no other token of its glories to man than the reflexion of its fires on mist and smoke; it burns for the Creator's eye alone. No foot of mortal can approach it.

"Hours passed as I watched the indescribable glories of the fire-fountain, its beauty of form, and its radiant reflexion on the precipices, eight hundred feet high, which wall it in, and listened to its surges beating, and the ebb and flow of its thunder-music. Then a change occurred. The jets, which for long had been playing at a height of 300 feet, suddenly became quite low, and for a few seconds appeared as cones of fire wallowing in a sea of light; then with a roar like the sound of gathering waters, nearly the whole surface of the lake was lifted up by the action of some powerful internal force, and rose three times with its whole radiant mass, in one glorious, upward burst, to a height, as estimated by the surrounding cliffs, of six hundred feet, while the earth trembled, and the moon and stars withdrew abashed into far-off space. After this the fire-fountain played as before. The cold had become intense, 11° of frost; and I crept back into the tent; those words occurring to me with a new meaning, 'dwelling in the light which no man can approach unto.'"—*The Hawaiian Archipelago:* By Isabella L. Bird; pp. 405–415.

* This actually occurred in June, 1832, when both craters were in a state of great activity together; Mauna Roa pouring out a lava stream, and the lava level of the molten lake of Kilauea being at its highest point.

The appearance of Kilauea has been described by many visitors. I select from these descriptions that of a gifted writer, whose literary excellences and faults are well known.*

If the Pacific Ocean were dried up, it would present the appearance of a gigantic lunar crater, occupying three-

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* "Shortly the crater came into view. I have seen Vesuvius since, but it was a mere toy, a child's volcano, a soup-kettle, compared to this. Mount Vesuvius is a shapely cone thirty-six hundred feet high; its crater, an inverted cone only three hundred feet deep, and not more than a thousand feet in diameter, if as much as that; its fires meagre, modest, and docile. But here was a vast, perpendicular, walled cellar, nine hundred feet deep in some places, thirteen hundred in others, level-floored, and *ten miles in circumference!* Here was a yawning pit upon whose floor the armies of Russia could camp, and have room to spare.

"Perched upon the edge of the crater, at the opposite end from where we stood, was a small look-out house—say three miles away. It assisted us, by comparison, to comprehend and appreciate the great depth of the basin—it looked like a tiny martin-box clinging at the eaves of a cathedral. After some little time spent in resting and looking and ciphering, we hurried on to the hotel.

"By the path it is half a mile from the Volcano House to the look-out house. After a hearty supper we waited until it was thoroughly dark, and then started to the crater. The first glance in that direction revealed a scene of wild beauty. There was a heavy fog over the crater, and it was splendidly illuminated by the glare from the fires below. The illumination was two miles wide and a mile high, perhaps; and if you ever, on a dark night and at a distance, beheld the light from thirty or forty blocks of distant buildings all on fire at once, reflected strongly against overhanging clouds, you can form a fair idea of what this looked like.

"A colossal column of cloud towered to a great height in the air immediately above the crater, and the outer swell of every one of its vast folds was dyed with a rich crimson lustre, which was subdued to a pale rose tint in the depressions between. It glowed like a muffled torch, and stretched upward to a dizzy height toward the zenith. I thought it just possible that its like had not been seen since the children of Israel wandered on their long march through the desert so many centuries ago over a path illuminated by the mysterious 'pillar of fire.' And I was sure that I now tenths of the whole surface of the earth, with a uniformly level bottom, except where broken here and there by isolated central volcanic peaks, like those of Owhyhee and Otaheite, rising abruptly to a height of 30,000 feet from the level of the ocean floor, and surrounded on all sides

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had a vivid conception of what the majestic 'pillar of fire' was like, which almost amounted to a revelation.

"Arrived at the little thatched look-out house, we rested our elbows on the railing in front, and looked abroad over the wide crater and down over the sheer precipice at the seething fires beneath us. The view was a startling improvement on my daylight experience. I turned to see the effect on the balance of the company, and found the reddest-faced set of men I almost ever saw. In the strong light every countenance glowed like red-hot iron; every shoulder was suffused with crimson, and shaded rearward into dingy shapeless obscurity! The place below looked like the infernal regions, and these men like half-cooled devils just come up on a furlough.

"I turned my eyes upon the volcano again. The 'cellar' was tolerably well lighted up. For a mile and a half in front of us, and half a mile on either side, the floor of the abyss was magnificently illuminated; beyond these limits the mists hung down their gauzy curtains, and cast a deceptive gloom over all that made the twinkling fires in the remote corners of the crater seem countless leagues removed—made them seem like the camp-fires of a great army far away. Here was room for the imagination to work! You could imagine those lights the width of a continent away—and that hidden under the intervening darkness were hills, and winding rivers, and weary wastes of plain and desert—and even then the tremendous vista stretched on, and on, and on!—to the fires and far beyond! You could not compass it—it was the idea of eternity made tangible—and the longest end of it made visible to the naked eye!

"The greater part of the vast floor of the desert under us was as black as ink, and apparently smooth and level; but over a mile square of it was ringed, and streaked, and striped with a thousand branching streams of liquid and gorgeously brilliant fire! It looked like a colossal railroad map of the State of Massachusetts done in chain lightning on a midnight sky. Imagine it—imagine a coal-black sky shivered into a tangled network of angry fire!

"Here and there were gleaming holes a hundred feet in diameter, broken in the dark crust, and in them the melted lava—the colour a dazzling white just tinged with yellow—was boiling and surging furiously; and from these holes branched numberless bright torrents in many directions, like the with a margin of lofty unbroken mural precipices, nowhere less than 12,000 feet in height, and, on the whole eastern margin, exceeding 20,000 feet in abrupt elevation.

The largest lunar crater (*Mare Crisium*) has a diameter less than 300 miles, and contains six central volcanic

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spokes of a wheel, and kept a tolerably straight course for a while, and then swept round in huge rainbow curves, or made a long succession of sharp worm-fence angles, which looked precisely like the fiercest jagged lightning. These streams met other streams, and they mingled with and crossed and recrossed each other in every conceivable direction, like skate tracks on a popular skating-ground. Sometimes streams twenty or thirty feet wide flowed from the holes to some distance without dividing—and through the opera-glasses we could see that they ran down small, steep hills, and were genuine cataracts of fire, white at their source, but soon cooling and turning to the richest red, grained with alternate lines of black and gold. Every now and then masses of the dark crust broke away and floated slowly down these streams like rafts down a river. Occasionally the molten lava flowing under the superincumbent crust broke through—split a dazzling streak, from five hundred to a thousand feet long, like a sudden flash of lightning, and then acre after acre of the cold lava, parted into fragments turned up edgewise like cakes of ice when a great river breaks up, plunged downward and were swallowed in the crimson cauldron. Then the wide expanse of the 'thaw' maintained a ruddy glow for a while, but shortly cooled and became black and level again. During a 'thaw,' every dismembered cake was marked by a glittering white border which was superbly shaded inward by aurora borealis rays, which were a flaming yellow where they joined the white border, and from thence toward their points tapered into glowing crimson, then into a rich, pale carmine, and finally into a faint blush that held its own a moment and then dimmed and turned black. Some of the streams preferred to mingle together in a tangle of fantastic circles, and then they looked something like the confusion of ropes one sees on a ship's deck when she has just taken in sail and dropped anchor—provided one can imagine those ropes on fire.

"Through the glasses, the little fountains scattered about looked very beautiful. They boiled, and coughed, and spluttered, and discharged sprays of stringy red fire—of about the consistency of mush, for instance—from ten to fifteen feet into the air, along with a shower of brilliant white sparks—a quaint and unnatural mingling of gouts of blood and snow-flakes!"—*The Innocents at Home:* By Mark Twain, pp. 186–189.

cones. The Pacific crater exceeds 10,000 miles in diameter, and contains twenty-six central volcanic cones in active exercise, besides numerous other extinct cones.

Volcanic Chain of Europasia.—The volcanic axis of Europasia is much smaller, less complicated, and less important than that of the Pacific. It follows a line from west to east, commencing at the Azores, passing along the axis of the Mediterranean, and thence along the Thianshan mountains to Lake Baikal, and the Altai mountains. The total length of the volcanic axis is 7000 miles, and its chief centres, from west to east, are:—

Pico (Azores), ...	7,613	feet.
Fogo (Cape de Verde Islands),	9,154	„
Teneriffe (Canary Islands), .	12,205	„
Etna, ...	10,872	„
Vesuvius,.	3,922	„
Volcano (Lipari), ...	1,304	„
Stromboli (Lipari), . . .	2,957	„
*Ararat, ...	17,112	„
Demavend, ...	21,500	„
Pe-shan (Thianshan), . . .	—	
Ho-tscheu (Thianshan), . .	—	

The remaining volcanoes of the earth are isolated and scattered up and down, apparently at random. The most important are—

Iceland, ...	Oeräfa Jokul, . .	5,927	feet.
	Snaefiall Jokul,. .	5,112	„
	Egafiall Jokul, . .	5,685	„
	Hecla,.	5,117	„
Antarctic Continent,	Mount Erebus, . .	12,366	„

* Extinct.

The following Table gives a summary of all the known terrestrial volcanoes, recent and extinct :—

	Total.	Active.
1. Europasia,*	18	10
2. Africa, ...	3	1
3. Australia, ...	0	0
4. The Americas, ...	115	53‡
5. Asiatic Coast Islands,† . .	203	119‡
6. Other Islands, ...	68	42
Total, ...	407	225

* Excluding Kamtschatka.

† Including Kamtschatka.

‡ These numbers, added together, give the 172 active volcanoes, which form the margin of the Pacific Ocean.

LECTURE III.*

THE LAWS OF CLIMATE, ATMOSPHERIC AND OCEANIC CIRCULATION.

LADIES AND GENTLEMEN,

The subject of my Lecture to-day is "Climate" past and present, and its dependence on the circulatory movements always going on in the Atmosphere and Ocean that surround our globe.

In the earliest periods of the earth's geological history, the entire surface of the globe was covered with water, with the exception of a few islands scattered here and there; whatever life existed was marine, and so uniform were the conditions of climate, that the same, or very similar, species of animals were capable of living, and did live, in almost every latitude of the earth; and varieties of what we now call climate did not occur to any great extent.

"Climate" may be defined as the complex effect of external conditions of heat and moisture upon the life of plants and animals. This complex but very intelligible idea explains how it happens that the surroundings of each plant or animal in its own country are such that it is with extreme difficulty, in many cases, that it can be removed and successfully *acclimatised* in another country, where the surroundings are somewhat different.† It is

* This Lecture was delivered on the 18th of March, 1876.

† The *potato* may be mentioned as an example; it was introduced into Europe from its native home in the Andes, and after 300 years of trial has shown, to our terrible cost, how frail an exotic it is.

also worthy of remark, that, with the exception of man, the more highly organised an animal is, the more unlikely is it to become acclimatised. The reason of this is, that a highly organised and differentiated plant or animal requires for its existence a larger number of external conditions than an organism of less developed type.*

Wherever we travel on the globe—in the torrid, temperate, or frigid zones—we see in the rocks, which form the skeleton of the earth, the forms and structure familiar to us in our own native land, but the vegetation that clothes those rocks varies from clime to clime, and recalls no home recollection to our minds: the trees that surround us, the birds that fly from branch to branch, and the wild animals that start up at our approach, revive in us no visions of our childhood and boyhood, nor of the country we have left behind.

About ninety years ago, the Scotch geologist Hutton pronounced his famous dogma—"*In the economy of the world I can find no traces of a beginning, no prospect of an end.*" Sir Charles Lyell spent his long and laborious life in writing commentaries on this text, and his followers have called themselves *Uniformitarians*, from their assertion of the uniformity of nature, at all times, past, present, and to come. It is, in reality, a shallow creed, refuted by many known facts in astronomy and geology; and if there be one science which teaches its falsehood more clearly than another, it is the science of geology, from which we learn that the present is unlike the past, and will probably be still more unlike the future. The doctrine of the

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* Suppose x, y, z, u, v, w, to be separate external physical conditions: if we have two animals represented by $\phi(x, y, z)$ and $F(x, y, z, u, v, w)$, the former will exist where x, y, z alone are found, but the latter will perish if u, v, w be not also present.

uniformity of nature is supposed to be a law of philosophy, but its acceptance is entirely due to the fact that we do not carry our observations over a sufficient period of time. When we deal with sciences like astronomy and geology, which are conversant with long periods of time, the dogma of uniformity vanishes into thin air.

The geological inscriptions recorded in the stony tables of the rocks, though mutilated by the hand of time, are written with the finger of God, and tell the same story that religion and philosophy have always taught—that everything in the Universe begins and ends, except its GREAT FIRST CAUSE.

The two chief factors in the complex problem of climate are heat and moisture, for all organic beings require certain conditions in the supply of these two elements to be fulfilled, as a necessity of their continued existence.

The amount of heat enjoyed by any place on the earth's surface depends upon the following conditions:—

The heat imparted by the sun.
The heat imparted by the solid earth.
The heat conveyed by atmospheric and ocean currents.

The amount of moisture enjoyed by any place on the earth's surface depends altogether upon one cause, viz., the amount of rainfall brought by atmospheric currents.

Geological Climates.—In the earlier periods of the earth's geological history, the heat which any part of its surface received from the interior was somewhat greater than at present, although much less than that received from the sun. The consequence was, that in all latitudes, high or low, there was a more uniform temperature; and, since at the same time the globe was nearly covered with water, the distribution of moisture was also nearly uniform. Hence physical conditions were highly favourable to the production of similar forms of organic life all over the globe.*

The past geological history of the earth may be divided into four great periods of time,† viz.:—

1. The Azoic.
2. The Lower Palæozoic.
3. The Upper Palæozoic.
4. The Neozoic.

* The heat received from the interior of the earth, at present, is sufficient to melt a layer of ice one quarter of an inch in thickness all over the surface of the globe; while that received from the sun would melt a layer 46 feet in thickness; being thus 2208 times greater than the heat dérived from the interior.

† Maximum thicknesses of Stratified Rocks (corrected by Professor Edward Hull, F.R.S.):—

		Feet.	Authority.	Country.
AZOIC.	Laurentian, . . .	32,750	Logan.	Canada.
60,750	Cambrian, ...	28,000	Aveline.	N. Wales.
PALÆOZOIC.	Lower Silurian, . .	27,000	Murchison.	N. Wales.
	Upper Silurian, . .	4,000	Murchison.	N. Wales.
	Dingle Beds, . . .	10,000‡	Jukes.	Co. Kerry.
	Devonian, ...	14,400	Dana.	N. America.
	Lower Carboniferous,	6,000	Hull.	England.
	Middle Carboniferous,	9,000	Hull.	England.
	Upper Carboniferous,	6,000	Hull.	England.
75,400	Permian, ...	4,000	Murchison.	Germany.
NEOZOIC.	Triassic, viz.:—			
	Keuper, ...	3,450	Hull.	England.
	Muschelkalk, . .	1,150	D'Orbigny.	Germany.
	Bunter, ...	2,150	Hull.	England.
	Jurassic, ...	5,000	D'Orbigny.	France.
	Wealden, ...	1,400	Jukes.	England.
	Cretaceous, . . .	12,400	D'Orbigny.	France.
	Tertiary, viz.:—			
	Eocene, ...	6,500	D'Orbigny.	France.
	Miocene, ...	7,000	Jukes.	Switzerland.
41,050	Pliocene, ...	2,000	Jukes.	Italy.

‡ This number is doubtful, as it probably includes overlying Devonian beds, which would be thus counted twice over. I have therefore reduced it to one half, in adding up the total thicknesses.

The Azoic rocks were deposited at a time when either no life, or very little, existed on the earth; and the Azoic age is separated by a long interval of time (of which we do not possess the geological record) from the Lower Palæozoic age which succeeded it. This lost interval is shown by the fact that the Lower Palæozoic rocks, in North America and Europe, rest unconformably upon the upturned and eroded edges of the Azoic strata.

During the interval which separates the Azoic age from the Lower Palæozoic age, the forms of Invertebrate life, which occur in the Lower Palæozoic age, were produced; and we find the Lower Palæozoic rocks abounding with forms of animal life, universally diffused, such as Trilobites and Orthoceratites, which cannot be regarded as lower than half way up the animal scale as it now exists.

No form of Vertebrate animal appeared on the earth until the close of the Lower* Palæozoic age, or after the lapse of fully half the entire duration of geological time.

During the Upper Palæozoic age, extensive land surfaces were in existence, on which flourished the luxuriant Flora of the Coal period—which served to depurate the atmosphere of its carbonic acid, and so rendered it capable of sustaining the life of animals of higher organisation than the Invertebrates of the Lower Palæozoic age.

Plants live by absorbing carbonic acid from the atmosphere, fixing the carbon in the wood, and returning oxygen to the air. Thus the formation of coal-beds, from the vegetation of the Carboniferous period, would reduce the carbonic acid in the atmosphere, and increase the oxygen. The formation of limestone strata (carbonate of lime) would act in the same direction, so far as absorbing

* The Lower Palæozoic age was essentially marine.

carbonic acid is concerned. Animals, on the other hand, live by absorbing oxygen and excreting carbonic acid; and the higher forms of animal life require most oxygen. An experiment of Dr. Prout's well illustrates the necessity of oxygen for the higher animals. He took a vessel containing four gallons of air, and having attached a mouth-piece to it, he held his nose, breathing with his mouth backwards and forwards into the closed vessel; up to the end of three minutes he felt no inconvenience, but shortly after, a singing sound commenced in his ears (from the brain-poisoning caused by the carbonic acid retained in the blood), and, on persevering for five minutes, he fell down insensible. Subsequent experiments showed that this occurred as soon as the carbonic acid in the vessel amounted to four per cent. of its entire volume.

It can be readily shown that a layer of coal, three inches thick, or a layer of limestone, fifteen inches thick, spread uniformly over the globe, if volatilised by heat would develop four per cent. of carbonic acid in the atmosphere, and immediately destroy all the warm-blooded animals on the surface of the globe.* The coal and

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* The calculation is made from the following data:—

Pressure of atmosphere per square inch = 15 lbs.
Grains in lb. avoirdupois, . . 7000.
Specific gravity of coal, . . . 1·5.
Specific gravity of limestone, . 2·5.
Weight of cubic inch of water, 252·5 grains.
Ratio of weight of carbon to carbonic acid = 6 : 22.
Ratio of weight of carbon to limestone, . = 6 : 50.

Hence, if x, y be the required thicknesses of the layers of coal and limestone, we find

$$x = \frac{15 \times 7000 \times 4 \times 6}{100 \times 1{\cdot}5 \times 252{\cdot}5 \times 22} = 3{\cdot}024 \text{ inches.}$$

$$y = \frac{3{\cdot}024 \times 1{\cdot}5 \times 50}{2{\cdot}5 \times 6} = 15{\cdot}12 \text{ inches.}$$

limestone existing in the stratified rocks, if spread over the whole earth, would supply vastly more than four per cent. of carbonic acid gas to the atmosphere.*

In the original condition of the earth, before its surface had cooled down to the temperature of boiling water, all the carbon of the globe must have existed in the atmosphere in the form of carbonic acid, which has been gradually eliminated by the conversion of silicates of lime into limestones, and by the fixing of the carbon in coal beds, produced by the action of plants upon the atmosphere.†

* The quantity of carbonic acid existing at present in our atmosphere is only 4 parts in 10,000—instead of 4 parts in 100, which is the minimum amount required to destroy the warm-blooded animals.

† It has been shown by the researches of Durocher, that the igneous rocks forming the surface of the globe may be divided into an upper and a lower layer, having different specific gravities and different chemical compositions. To these he gives the names of Acid and Basic Magmas. They have the following compositions :—

	Upper Layer or Acid Magma.		Under Layer or Basic Magma.	
	Per cent.	Oxygen.	Per cent.	Oxygen.
Silica,	71·0	36·86	51·5	26·50
Alumina,	16·0	7·47	16·0	7·47
Potash,	4·5	0·76	1·0	0·17
Soda,	2·5	0·64	3·0	0·76
Lime,	1·0	0·28	8·0	2·27
Magnesia,	1·0	0·40	6·0	2·40
Iron and Manganese Oxides,	2·5	0·75	13·0	2·88
Water, &c.,	1·2	1·06	1·3	1·15
Totals,	99·7	48·22	99·8	43·60
Specific Gravity,	2·65		2·95	

The upper layer is marked by the abundance of Silica and by the scarcity of Lime, Magnesia, and Iron.

The lower layer is marked by the diminution of Silica, Potash and Soda, and by the increase of Lime, Magnesia, and Iron.

Both layers are marked by the absence of Carbon, which is found in the stratified rocks only.

The Upper Palæozoic age, in which the chief depuration of the atmosphere took place, is characterised by the appearance of the lower forms of Vertebrate life, viz., fishes and reptiles, which are totally absent from the Lower Palæozoic age.

Between the Upper Palæozoic and Neozoic ages there occurs another interval of time, of which we have lost the geological record, similar to the missing interval between the Azoic and Lower Palæozoic ages, but of much shorter duration. This interval of time is shown by the general unconformity of the Permian and Triassic rocks.

During this lost interval, the lower forms of Mammalian life were produced, viz., the Marsupials; and many important changes took place in all forms of organic life—changes which fully justify the use of the terms Palæozoic and Neozoic.

The change in the forms of higher animals became most rapid in the interval between the Cretaceous and Tertiary strata; an interval marked by enormous changes in physical geography, which elevated the chief part of the continent of Europasia, and in North America abolished the great sea which stretched from the Gulf of Mexico to the Arctic Ocean, converting it into great inland lakes.

The high temperature which characterised the Palæozoic times was mainly due to the heat of the sun having been somewhat greater than its present heat, and the effects of this greater heat appear to have continued down to very recent epochs. For example, it can be shown that far inside the Arctic Circle, in the geological periods of the Neozoic age called Triassic and Jurassic, animals lived that could only have existed in tropical or sub-tropical climates.

(1). *Climate of the Parry Islands in the Jurassic Period.*—Captain M'Clintock found in the Parry Islands, on the north coast of America, at Point Wilkie, in Prince Patrick's Island, Lat. 76° 20′, tropical shells, and drew the attention of geologists to the difficult task of providing a tropical climate inside the Arctic Circle, to accommodate the habits of the animals that lived there in Jurassic times. The tropical fossils found in the Parry Islands were:—

Ammonites M'Clintocki (M'Clintock).
Monotis septentrionalis „
Pleurotomaria sp. „
Nucula sp. „
Ichthyosaurus sp. (vertebræ) (Sir Edward Belcher).*
Teleosaurus sp. (vertebræ) (Capt. Sherrard Osborne).†

The *Teleosaurus* was a reptile closely resembling the Gavial of India, which is found nowhere outside the Tropics, and requires warmer water than the alligator of America. The alligator thrives in the neighbourhood of New Orleans, whose climate is represented by the following figures:—

Mean Monthly Temperature of New Orleans.

January, . .	54°·8 F.	July, . . .	81°·6 F.
February, . .	56 ·4 „	August, . . .	81 ·6 „
March, . . .	62 ·9 „	September, . .	78 ·5 „
April, . . .	69 ·0 „	October, . .	69 ·8 „
May, ...	74 ·8 „	November, . .	60 ·2 „
June, . . .	79 ·9 „	December, . .	56 ·0 „

Yearly Mean, . . . 68°·7 F.

Reptiles requiring a climate such as is indicated by the preceding Table lived, in the Jurassic Period, within 900

* Exmouth Island, Lat. 77° 12′ N. (only 900 miles from the Pole).
† Rendezvous Hill, at north-west extremity of Bathurst Island, Lat. 77° N.

miles of the North Pole, where the present climate is represented by the following figures :—

Mean Monthly Temperature of Melville Island.

January, . . .	− 31°·3 F.	July, ...	+ 42°·4 F.
February, . .	− 32 ·4 „	August, . .	+ 32 ·6 „
March, . . .	− 18 .2 „	September, .	+ 22 ·5 „
April, ...	− 8 ·2 „	October, . .	− 2 ·8 „
May, ...	+ 16 ·8 „	November, .	− 21 ·1 „
June, ...	+ 36 ·2 „	December, .	− 21 ·6 „

Yearly Mean, ... + 1°·2 F.

(2). *Climate of Spitzbergen in the Triassic Period.*—The Triassic beds of Spitzbergen, Lat. 79° N., have afforded species of—

Nautilus, *Ceratites*, *Monotis*,
Ammonites, *Halobia*,

closely allied to, if not identical with, the St. Cassian beds of South Austria.

(3). *Climate of Alaska in the Triassic and Jurassic Periods.*—In the neighbourhood of Cook's Inlet, in Alaska, Lat. 60° N., shells characteristic of the Triassic and Jurassic Periods have been found :—

Monotis,	Triassic,*
Aucella,	Jurassic,
Ammonites Wosnessenski,	„
Ammonites biplex,	„
Belemnites paxillosus,	„
Pleuromya unioides,	„

and similar fossils are found along the Pacific coast of North America.

* Triassic slates containing *Monotis* and *Halobia* have been recently discovered in places widely separate from each other, all over the globe, viz. :—New Zealand, New Caledonia, N. W. America, Upper India, beyond the Himalayas, and in Spitzbergen.

It is not possible to explain the occurrence of tropical animals, in the three above-mentioned localities, by any change in the position of the earth's axis, even if so great an amount of change as would be required were possible. This statement can be proved as follows:—Let a great circle be drawn, joining Spitzbergen with Cook's Inlet, Alaska: this circle will pass nearly through the North Pole. In order to explain the tropical climate of these two localities, and also of the Parry Islands, the Pole must be displaced at right angles to the great circle joining Spitzbergen and Alaska, along the meridian Long. 117° E., nearly that of Pekin. The present difference of latitude between New Orleans and Spitzbergen is 45°; so that, in order to make the Arctic regions tropical, we must move the North Pole 45° on the meridian of Pekin, bringing it within 300 miles to the north of that city. Hence it follows that, during the Triassic Period, Pekin lay under the North Pole, covered by the Polar ice-cap.

Let us now consider what the South Pole was doing. It had moved on the opposite meridian, and had reached the mouth of the Rio Negro, on the east coast of Patagonia, about 1000 miles to the S.S.E. of Valparaiso and the Chilian Andes. Jurassic strata have been found in the Chilian Andes at 34° S., containing the tropical *Ammonites biplex*, which is found also in Alaska, 60° N., and in Europe. This locality lies within 700 miles of the necessary position of the South Pole, and cannot have enjoyed a tropical climate. The proposed alteration of the North Pole is consistent with the occurrence of tropical animals in the Parry Islands, in Spitzbergen, and in Alaska; while the proposed alteration of the South Pole would admit of tropical animals in New Zealand and New Caledonia; but the existence of Jurassic Ammonites within 700 miles of the South Pole in Chili is fatal to the proposed shifting of the axis of rotation, even if that were otherwise allowable to the extent required.

The Climate of the Arctic Regions during the Tertiary Miocene Period.—There is abundant evidence to show that, during the Miocene Tertiary Period, the northern parts of the continents of America and Europasia possessed a nearly identical forest vegetation, with a temperate climate, resembling that now enjoyed by the northern parts of Italy, such as Lombardy.

The localities in which the *lignite* beds are found, that indicate the former existence of this remarkable vegetation, are the following:—

Greenland (Disco), Lat. 70°.
*Grinnell Land, Lat. 81° 44′.
Spitzbergen (west coast), Lat. 77°.
Alaska and Mackenzie River, Lat. 70° to 60°.

* "Near Discovery Harbour, where H. M. S. 'Discovery' wintered in 1875-6, in about 81° 45′ N. lat., and 67° 45′ W. long., a bed of lignite, from 25 to 30 feet thick, was found, resting unconformably upon the azoic schists of which Grinnell Land chiefly consists. The lignite was overlain by black shales and sandstones, the former containing many remains of plants; and above these there were, here and there, beds of fine mud and glacial drift, containing shells of marine Mollusca of species now living in the adjacent sea. This glacial marine deposit occurs up to levels of 1000 feet, indicating a depression and subsequent elevation of the region to at least this extent.

"Remains of 25 species of plants were collected by Capt. Feilden, and 18 of these are known from Miocene deposits of the arctic zone. The deposit is therefore no doubt Miocene. It has 17 species in common with Spitzbergen (78° 79′ N. lat.), and 8 species in common with Greenland (70° 71′ N. lat.). With the Miocene Flora of Europe it has 6 species in common; with that of America (Alaska and Canada) 4; with that of Asia (Sachalin) 4 also. The species found include 2 species of *Equisetum*, 10 Coniferæ, *Pragmites*, *Œningensis*, *Carex Nouarsoakensis*, and 8 Dicotyledons, The genus *Sequoia** (Redwood) has representatives in all these localities, and one Greenland species, *S. Sternbergi*, is very near the great Californian species, *S.* (*Wellingtonia*) *gigantea*, which now lives in California. In Spitzbergen there are found in the Miocene beds two species of *Libocedrus*, viz., *L. Sabiniana* and *L. gracilis*, which are closely related to species now living in California among the Redwoods, and in the Andes of Chili. The common *Taxodium* (cypress) of the Southern States occurs fossil in

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namely, *Populus arctica*, *Betula prisca* and *Brongniarti*, *Corylus Macquarrii* and *insignis*, *Ulmus borealis*, *Viburnum Nordenskiöldi*, and *Nymphæa arctica*.

"Of the Conifers, *Torellia rigida*, previously known only by a few fragments from Spitzbergen, is very abundant, and its remains show it to have been allied to the Jurassic genera *Phoenicopsis* and *Baiera*, the former in its turn related to the Carboniferous *Cordaites*, and among recent Conifers, to *Podocarpus*. Other Conifers are, *Thuites Ehrenswärdi ?*, *Taxodium distichum miocenum* (with male flowers), *Pinus Fieldeniana* (a new species allied to *P. strobus*), *Pinus polaris*, *P. abies* (twigs covered with leaves), a species of *Tsuga* (*Pinus Dicksoniana*, Heer), and a white Spruce of the group of *Pinus grandis* and *cariocarpa*. *Pinus abies*, which occurs here and in Spitzbergen, did not exist in Europe in Miocene times, but had its original home in the extreme north, and thence extended southwards; it is met with in the Norfolk forest-bed, and in the interglacial lignites of Switzerland. Its present northern limit is 69½° N., and it spreads over 25° of latitude. *Taxodium distichum*, on the contrary, spread in Miocene times from Central Italy to 82° N. latitude, while at present it is confined to a small area.

"*Betula Brongniarti*, Ett., is the only European species from Grinnell Land not previously known from the arctic zone.

"The thick lignite-bed of Grinnell Land indicates a large peat-moss, probably containing a lake in which the water-lilies grew; on its muddy shores stood the large reeds and sedges, the birches, poplars, *Taxodia*, and *Torelliæ*. The drier spots and neighbouring chains of hills were probably occupied by the pines and firs, associated with elms and hazel-bushes. A single elytron of a beetle (*Carabites Feildenianus*) is at present the sole evidence of the existence of animals in this forest-region.

"The nature of the Flora revealed by Capt. Feilden's discoveries seems to

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* The Big Trees of California belong to this genus.

the Miocene beds of Spitzbergen, Greenland, and Alaska.* All the genera mentioned below are found in Greenland and Spitzbergen, as well as in Alaska; and, according to Professor Heer, indicate a mean annual temperature of 48° F. during the Miocene period in localities where the mean annual temperature is now as low as zero. During the Eocene Tertiary Period, according to Ettingshausen, there flourished in the Tyrol a Flora which indicates a mean annual temperature between 74° F. and 81° F.; the

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confirm and extend earlier results. It approaches much more closely to that of Spitzbergen than to that of Greenland, as might be expected from the relative positions of the localities; and the difference is the same in kind as that already indicated by Prof. Heer between Spitzbergen and Greenland, and would indicate the same kind of climatic difference. Nevertheless, the presence of *Taxodium distichum* excludes arctic conditions, and that of the water-lily indicates the existence of fresh water, which must have remained open a great part of the year. Representatives of plants now living exclusively in the arctic zone are wanting in the Grinnell Land deposit; but on the other hand most of the genera still extend into that zone, although they range in Grinnell Land from 12° to 15° further north than at present."—'Notes on Fossil Plants discovered in Grinnell Land by Capt. H. W. Feilden, Naturalist to the English North Polar Expedition.' By Prof. Oswald Heer, F.M.G.S.—*Abstract of Proceedings, Geological Society of London*, Nov. 7, 1877.

* The following genera have been described by Prof. Heer, as found at Mackenzie River and Alaska; there are many species of each:—

Planera.	*Juglans* (Walnut).
Castanea (Chestnut).	*Carya* (Hickory).
Diospyros (Ebony tree).	*Rhus* (Sumach).
Vaccinium (Bilberry).	*Vitis* (Vine).
Acer (Maple).	

All these are indicative of a Lombardic climate, for their living representatives (excepting *Vacciniam* and *Acer*), do not extend into the N. Temperate region.

species being largely Australian in character. According to the same author, the Miocene Flora of Vienna was sub-tropical, corresponding to the mean annual temperature between 68° F. and 79° F., and closely resembling that of sub-tropical America. It can be shown, by a method similar to that employed for the Triassic and Jurassic Periods, that the North Pole was, practically, in the same place during the Miocene Period that it now occupies.

If we join the Mackenzie River and Spitzbergen by the arc of a great circle, the North Pole must be moved, at right angles to this arc, away from Greenland, through 30°, in order to give all these northern localities a Lombardic climate. The direction in which the Pole must be moved is on the meridian of Nagasaki (one of the Japanese Islands), and it reaches a point close to Yakutsk, within 800 miles of the peninsula of Kamtschatka and the Island of Saghalien, off the Amoor.

Here we meet with a difficulty similar to that offered by the South Pole in the Triassic Period. The Island of Saghalien and the peninsula of Kamtschatka contain Miocene coal-beds, requiring at least a sub-tropical climate, which would be impossible under the supposed circumstances. Also, the Islands of Yesso, Nagasaki, and Kiusiu, somewhat farther off, contain similar Miocene coal-beds.*

* "Most of the arctic expeditions within the century have lighted on traces of a comparatively luxuriant vegetation in regions now covered with perpetual ice; and from Prince Patrick's Island to the east coast of Greenland remains of Miocene forests have been met with. The upright position of the trees in many cases proves that the forests grew on the sites where now are found their remains, and that we have here no chance remains of driftwood carried by currents from warmer regions, as was the opinion of the early navigators. The recent expedition of Captain Nares proved that this Miocene Flora reached to higher latitudes still. Almost at the northern limit of *The Discovery's* investigation, in 81° 44′ N. Latitude, a

It is very remarkable that, while there exists so many proofs of a warm climate near the North Pole in former geological periods, there is no evidence at all of cooler climates having ever existed in the Tropics. It was at one time thought that an exception to this statement occurred in the Island of Java, where, it was asserted, a Tertiary Flora was to be found, indicating rather a temperate than a tropical climate. The full investigations of Göppert, however, have satisfactorily shown that the Tertiary Flora of Java is of Eocene age, and essentially tropical in character, containing numerous specimens of *Palms*, *Musas*, *Peppers*, *Laurels*, *Magnolias*, and *Proteaceæ*.

From all the preceding facts, we are entitled to conclude that, down to so recent a period as the Miocene Tertiary, climates depended chiefly on the internal heat derived from the cooling earth. As we are precluded from assigning large changes in the position of the poles as a cause for large changes of climate, a very interesting question thus arises as to the sense in which we call the Miocene Tertiary a recent period. This question may be thus discussed:—We may regard the plants and animals preserved in the fossil state in the Arctic regions as self-registering thermometers, recording for us the mean temperature of those regions at successive epochs, marking so

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bed of coal of this age was discovered, agreeing in position with the Miocene coal-beds of Disco. Amongst other fossils, both localities have yielded remains of evergreens. The Flora is not tropical, but temperate, approaching in character to that of northern Italy.

"Remarkable as are these facts in a region so near the present Pole, they are not unique. Spitzbergen and the islands of New Siberia, in Miocene times, supported a vegetation pointing to like conditions of climate. Further east the coal-fields of Saghalien seem to be likewise of Mid Tertiary age, and those of Yesso I believe belong to the same epoch. In the Island of Kiusiu, Miocene rocks are developed to an enormous extent; the volcanic many fixed points on the earth's thermometrical scale. In addition to these, we have the present temperature of the Arctic regions directly observed, and two other temperatures determined by physical and physiological conditions: these are the temperature of boiling water, and the temperature at which albumen coagulates. No stratified rocks could have been formed on the earth before the first point of cooling down was reached, because there was no water to form them; and no life could have existed on the earth until it cooled down to the latter temperature.

We thus find, in the Arctic regions, the following successive temperatures:—

1. . .	212° F., . .	Boiling water.
2. . .	122° F., . .	Coagulation of albumen.
3. . .	68° F., . .	Triassic and Jurassic Periods, Climate of Gulf of Mexico.
4. . .	48° F., . .	Miocene Tertiary Period, Climate of Lombardy.
5. . .	32° F., . .	Climate of Labrador.
6. . .	0° F., . .	Present climate.

conglomerates, shales and sandstones of Nagasaki seem to exceed 5000 feet in thickness, and the upper portion of this very important series contained, prior to its denudation, one of the richest coal-fields in the world. In the Island of Takosima, where a good section is obtainable, there exists within a thickness of strata of a little more than 300 feet no less than fourteen beds of coal varying from 1 to 8 feet thick, and whose united thickness amounts in the aggregate to about 57 feet. Some of these rest on shales containing remains of the old Flora, which bears a close resemblance to that of the district at the present day. Unfortunately this rich fossil Flora remains as yet undescribed. The fossil Flora of Spitzbergen and New Siberia finds its nearest analogue in that of north China and Japan, so that we are compelled to believe in the former extension of a similar Flora over the intermediate districts, as well as in the occurrence of very similar conditions of climate." —*The Border Lands of Geology and History* (pp. 28–9); by Thomas W. Kingsmill; Shanghai, 1877.

The interval between the first and second corresponds to the Azoic rocks; that between the second and third, to the Palæozoic rocks; and that between the third and fourth, to the Neozoic rocks. Now, although we do not know the co-efficient that fixes the rate of cooling of the sun-heated earth suspended in cold space, we know the law of such cooling, and can compare, by calculation, the *proportions* of the foregoing intervals of time with each other.* When this calculation is made, we obtain—

Azoic Time .	(212°–122°), . .	33·0	per cent.
Palæozoic Time	(122°– 68°), . .	41·0	„
Neozoic Time	(68°– 48°), . .	26·0	„
		100·0	per cent.

At page 77 I have given a Table of the maximum thicknesses of the Stratified Rocks, prepared with the assistance of Professor Edward Hull, F.R.S. From that Table I find—

Azoic Rocks, ...	60,750	feet.
Palæozoic Rocks, ...	75,400	„
Neozoic Rocks, ...	41,050	„
	177,200	feet.

Converting these numbers into percentages, and compar-

* The law of cooling is expressed by the equation :—

$$x = \frac{1}{N}\frac{\log\left(\frac{a^t - 1}{a^t}\right)}{\log(a)} + C;$$

where

x = time,

t = temperature above that of equilibrium, in Centigrade degrees,

a = 1·0077,

N, C, unknown constants.

ing them with the percentages of time found from the theory of a cooling globe, we have—

Scale of Geological Time.

Period.	From Theory of Cooling of Sun-heated Globe.	From Maximum Thickness of Strata.
Azoic, ...	33·0 per cent.	34·3 per cent.
Palæozoic, ...	41·0 ,,	42·5 ,,
Neozoic, ...	26·0 ,,	23·2 ,,
Total, . . .	100·0 ,,	100·0 per cent.

The agreement between these figures, derived from entirely independent sources, is very remarkable, and strongly justifies the principle held by many geologists, that

The proper relative measure of geological periods is the maximum thickness of the strata formed during those periods.

This is equivalent to supposing the rate of deposition of strata to have been constant during the period contained in the Table, which is probable enough on other grounds; for although the rock-making forces were greater when the heat was greater, it must be remembered that the land surfaces to be denuded were smaller, and that the sea bottoms, on which the *debris* was to be spread, were also greater. The calculation founded on the theory of a cooling globe cannot, with safety, be carried down too near the point of equilibrium temperature, which is the Fahrenheit zero (for the Arctic regions under consideration); but we may, without risk, extend the computation from 48° F. to 32° F.; that is, we may estimate the interval of time, from the Miocene Tertiary epoch, when the Parry Islands and northern Greenland enjoyed a Lombardic climate, to the epoch (probably long past) when those districts suffered a climate like that of Labrador, but better than that they now have.

The result of the calculation, when reduced to the same scale as that used in the Table, is 32 per cent., a result the importance of which will be better seen by the following propositions which flow from it:—

1. *The greater interval of time now separates us from the Miocene Tertiary epoch than that which was occupied in producing all the secondary and tertiary strata, from the Triassic epoch to the Miocene epoch.*

2. *The enormous interval of time that separates us from the Miocene epoch affords ample opportunity for the development of the gigantic Mammals, which are erroneously supposed to have somewhat suddenly made their appearance on all our continents, and to have disappeared as suddenly.*

All the foregoing facts point to the conclusion that the present condition of the earth's surface is profoundly different from its condition in the geological periods when climates depended partly on the internal heat of the earth, but chiefly, on the greater heat of the sun. The doctrine of "uniformity," so persistently held by Lyell and his followers, breaks down when we compare, with any accurate detail, our present climates with those of former periods.

Although we must proceed with extreme caution when we reason from the present to the past, yet it is impossible for us not to attempt to do so, and try to solve the mystery that surrounds the question of the duration of geological time. We must endeavour to lift the veil of Isis, and compel our Mother Earth to tell her age.

The following Table contains estimates of the number of years required by the several rivers to scrape off one foot from their respective rain-basins, and carry the materials to the sea, where it is to be spread out on the sea bottoms by ocean currents. The figures are obtained by carefully measuring, at frequent intervals, the total discharge of water and the total weight of the mud held in suspension. This weight of mud, reconverted into surface rock, must cover the entire rain-basin to a depth of one foot spread uniformly.

Rates of Denudation of Rain-Basins lowered One Foot.

Ganges, ...	2358	years.
Mississippi, ...	6000	„
Hoang Ho, ...	1464	„
Yangtse Kiang, ...	2700	„
Rhone, ...	1528	„
Danube, ...	6846	„
Po, ...	729	„
Mean, . . .	3090	years.

From this Table it appears that atmospheric agencies are capable, at present, of lowering the land surfaces at the rate of one foot per three thousand years; but since the sea bottoms are to the land surfaces in the proportion of 145 to 52, the rate at which (under present circumstances) the sea bottoms are becoming silted up, that is to say, the present rate of formation of strata, is *one foot in* 8616 *years.* If we admit (which I am by no means willing to do) that the manufacture of strata in geological times proceeded at *ten times* this rate, or at the rate of one foot for every 861·6 years, we have, for the whole duration of geological time, down to the Miocene Tertiary epoch,

$$861{\cdot}6 \times 177{,}200 = 152{,}675{,}000 \text{ years.}$$

To this must be added at least one-third, as before shown, to bring in the period from the Miocene Tertiary to the time when the Parry Islands and north Greenland had the climate of Labrador.

This gives for the whole duration of geological time a *Minimum* of *two hundred millions of years.*

Modern Climates.—Modern climates (unlike the climates of geological periods) are completely independent of the internal earth-heat, and depend mainly on the heat received from the sun, and distributed over the globe by means of the system of atmospheric and oceanic currents which are in regular and continual motion.

The atmosphere and ocean may be regarded as satellites of the earth, capable of tidal and other motions that do not influence the earth herself. The relative masses of the earth's satellites are—

Moon, ... $\frac{1}{80}$,

Ocean, ... $\frac{1}{4,639}$,

Atmosphere, ... $\frac{1}{1,125,000}$.

If the earth possessed neither an atmosphere nor an ocean, and had a uniform surface, the temperature of any place would depend only on the latitude and time of year and day, or—

$$\theta = F(\lambda, \delta, h);$$

where

θ = temperature of place,
λ = latitude of place,
δ = declination of sun,
h = hour of day;

and the form of the function could be determined by theoretical considerations. In the actual state of things, the question of temperature involves, in addition to the latitude and time of year, the distribution of land and water, on which the atmospheric and oceanic circulation depend, and the height above the sea-level.

Circulation of the Atmospheric Currents.—We are not able, in the present state of our knowledge, to form a complete mathematical theory of atmospheric currents, caused by the unequal expansion of the air by solar heat, and the evaporation from the ocean due to the same cause. But we are able to satisfy the equations of motion by a special arrangement of all the atmospheric currents and barometric pressures, which gives us a solution of the problem that explains every important fact.*

We suppose a constant system of regular atmospheric currents, in which the accelerating and retarding forces balance each other, so as to leave the motion uniform and permanent. It is easy to see that in a permanent condition of dynamical equilibrium, like that existing in the atmospheric currents, there must be variations in the barometric pressures corresponding to the conditions of the currents in each part of the system. The connexion between the barometric pressures and the motions of the currents may be thus expressed:—*A line of low barometric pressure will correspond to ascending currents in the atmosphere, and a line of high barometric pressure will correspond to descending currents in the atmosphere.*

If AOB (Fig. 9) be a portion of the surface of the earth, and currents AO and BO, moving in opposite directions, meet at the point O, the greater part of their

* This solution is due to Mr. W. Ferrel, of the United States Coast Survey—*vide* "The Motions of Fluids and Solids relative to the Earth's Surface"; New York, 1860.

momentum is destroyed, but the residual current will possess an ascending motion, as shown in the figure; and the barometric pressure will be therefore *less* at O than at either A or B.

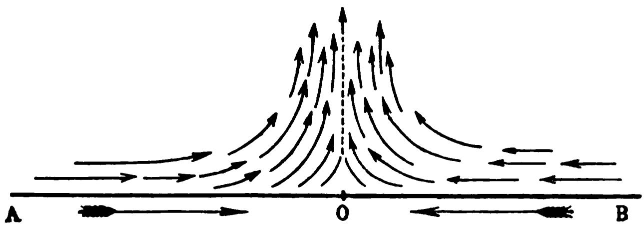

Fig. 9.

In like manner when, from any cause, there exist vertical descending currents at O (Fig. 10), dividing into opposite currents OA and OB, the barometric pressure must be *greater* at O, than at either A or B.

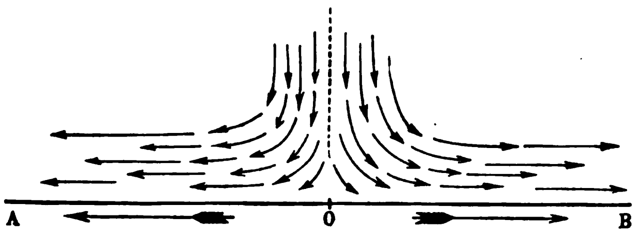

Fig. 10.

Hence a careful study of the distribution of the barometric pressures all over the globe affords us a key to the problem of the general atmospheric circulation. The following Table contains the mean barometric pressures for January, July, and the whole year, at each 5° of latitude, taken from the most recent sources.*

* "Meteorological Researches for the use of the Coast Pilot," part i., (Washington, 1877); W. Ferrel.—*United States Coast Survey.*

Mean Barometrical Pressures, varying with the Latitude, expressed in millimeters.

Latitude.	January.	July.	Annual.
80° N.	760·4 mm.	760·6 mm.	760·5 mm.*
75 „	760·2 „	758·8 „	760·0 „
70 „	759·0 „	758·2 „	758·6 „
65 „	†758·8 „	†757·6 „	†758·2 „
60 „	759·7 „	757·7 „	758·7 „
55 „	761·0 „	758·4 „	759·7 „
50 „	762·1 „	759·3 „	760·7 „
45 „	763·0 „	760·0 „	761·5 „
40 „	763·6 „	760·4 „	762·0 „
35 „	‡764·1 „	‡760·7 „	‡762·4 „
30 „	763·4 „	760·0 „	761·7 „
25 „	762·0 „	758·8 „	760·4 „
20 „	760·6 „	757·8 „	759·2 „
15 „	759·3 „	†757·3 „	758·3 „
10 „	758·4 „	757·4 „	†757·9 „
5 „	758·0 „	757·9 „	758·0 „
0 „	757·4 „	758·6 „	758·0 „
5° S.	†757·1 „	759·5 „	758·3 „
10 „	757·4 „	760·8 „	759·1 „
15 „	758·2 „	762·2 „	760·2 „
20 „	759·5 „	763·9 „	761·7 „
25 „	760·8 „	765·6 „	763·2 „
30 „	‡761·3 „	‡765·7 „	‡763·5 „
35 „	760·6 „	764·2 „	762·4 „
40 „	759 1 „	761·9 „	760·5 „
45 „	756·3 „	758·3 „	757·3 „
50 „	752·7 „	753·7 „	753·2 „
55 „	748·2 „	748·2 „	748·2 „
60 „	—	—	743·4 „
65 „	—	—	739·7 „
70 S.	—	—	738·0 „

* The mean annual pressure found recently north of 80° seems to show another decrease in going north :—

"Polaris," . . . . 29·970 inches.
"Discovery," . . . . 29·887 „
"Alert," . . . . 29·869 „

The mean of these is 760 millimeters.—*Proc. R. Soc.*, vol. xxvi., p. 436.

† Minimum. ‡ Maximum.

An examination of the foregoing Table shows:—

1. A *minimum* pressure, all the year round, along the parallel 65° N. (The North Polar Calms.)

2. A *maximum* pressure, all the year round, along the parallel 35° N. (The Calms of Cancer.)

3. A *minimum* pressure, varying with the sun's position, from 5° S. to 15° N., and having a mean position along the parallel of 6° N. (The Equatorial Calms.)

4. A *maximum* pressure, all the year round, along the parallel 28° S. (The Calms of Capricorn.)

If we plot the last column of the preceding Table, we shall obtain the diagram (Fig. 11), in which I have inserted arrows to represent the ascending and descending currents of the air. An inspection of the figure shows—

1. Northerly winds from 6° N. to 35° N.
2. Southerly winds from 6° N. to 28° S.
3. Southerly winds from 35° N. to 65° N.
4. Northerly winds from 28° S. to 70° S.
5. Northerly winds from 65° N. to 80° N.

Of these five systems of winds, the first two are the foundations of the Trade winds; the next two form the Antitrade winds; and the fifth gives origin to the North Polar winds.

The directions of all these north and south winds are changed by the rotation of the earth in the following manner:—

At any spot on the earth's surface, the component of rotation round the vertical passing through the zenith is $\omega \sin \lambda$, where ω is the earth's angular velocity, and λ is the latitude of the place. In Foucault's celebrated pendulum experiment, this component of rotation is made

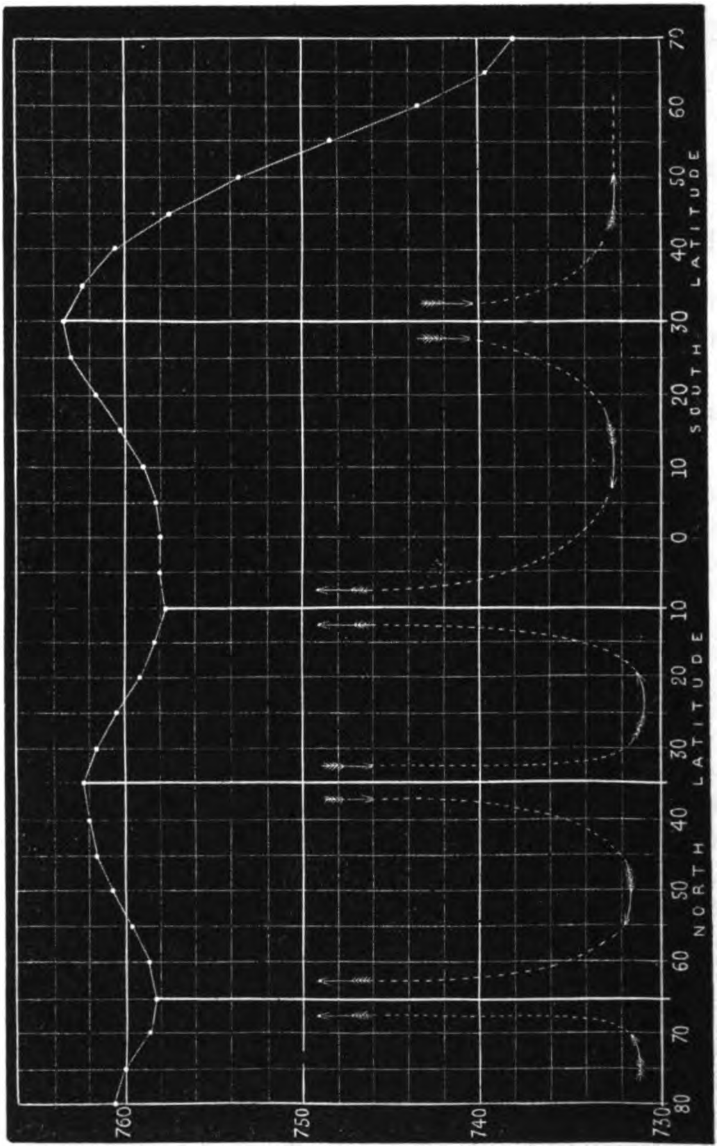

Fig. 11.

The horizontal co-ordinates are degrees of latitude. The vertical co-ordinates are barometrical pressures expressed in millimeters.

visible to the eye. This rotation is left-handed in the northern hemisphere, and right-handed in the southern hemisphere.

Let O (Fig. 12) be any point in the northern hemisphere, and let a circle be described on the horizon, having that point as centre. Let a cannon ball be fired in the direction OA, at the moment when the point *a* lies

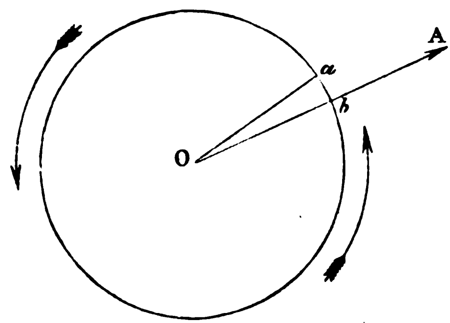

Fig. 12.

in the line OA; the cannon ball is therefore aimed at *a*; but it will strike *b*, lying to the right of *a*, because all the points of the horizon are revolving with a left-handed rotation in the direction indicated by the arrows.

What is true of a cannon ball will be also true of a current of air or water; and hence it follows that a wind blowing in any direction in the northern hemisphere is deflected to the *right*, by an amount proportional to sin λ; and, *vice versâ*, a wind blowing in any direction in the southern hemisphere is deflected to the *left*, by a similar amount depending on the latitude. Hence northerly winds in the northern hemisphere are converted into north-easterly winds, and southerly winds into south-westerly winds; and, *vice versâ*, southerly winds in the southern hemisphere are converted into south-easterly winds, and northerly winds are converted into north-westerly winds.

The five systems of winds described on p. 99, as necessary to account for the variations of atmospheric pressure, are converted by the rotation of the earth into the following :—

1. North-east Trades, . . 6° N. to 35° N.
2. South-east Trades, . . 6° N. to 28° S.
3. South-west Antitrades,† 35° N. to 65° N.
4. North-west Antitrades,† 28° S. to 70° S.*
5. North-east Arctic Winds, 65° N. to 80° N.

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* And, probably, as far as the South Pole itself.

† It will be noted that the Southern Trades and Antitrades occupy a broader belt in Latitude than the corresponding Northern winds :—

North-east Trades, ...	(35° N. – 6° N.)	= 29°.
South-east Trades, ...	(6° N. + 28° S.)	= 34°.
South-west Antitrades, . . .	(65° N. – 35° N.)	= 30°.
North-west Antitrades, . . .	(70° S. – 28° S.)	= 42°.

Both classes of winds are therefore more constant and better developed in the southern hemisphere than in the northern.

The following letter shows the power of the North-west Antitrades in New Zealand :—

"1, Willow Terrace, Blackrock, Co. Dublin.
"*March* 27, 1876.

"Dear Sir,

"An interesting example of one part of your lecture occurs in New Zealand. At the risk of telling you of a phenomenon which you are well acquainted with, I shall describe to you what is known to dwellers on the Canterbury plains as a 'Nor-wester.'

"These plains are about 100 miles long by 30 to 40 miles wide, reaching from the sea on the east to a range of mountains varying from 8 to 12 thousand feet in height. Strong winds are very prevalent on the plains :

It will be observed that the northern and southern hemispheres agree in having Trade and Antitrade winds; but that the northern hemisphere develops, to the north of the Antitrades, a system of north-east Polar winds, which finds no counterpart, so far as we know, in a system of south-east Polar winds, in the southern hemisphere.

This arises from the unequal distribution of land and water in the two hemispheres.

In Fig. 13, I show the mean vertical and horizontal motions of the atmosphere, in the case of a *homogeneous surface* of the earth in the two hemispheres.

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that from the nor-west is the strongest and most furious that blows. At the foot of the hills and on the plains it is a very dry and often a hot wind, unaccompanied with rain—the sky is a peculiar deep dull blue, and any clouds there may be seem not to move.

"On the tops of the range there rest heavy black clouds which, notwithstanding the furious wind, remain fixed. In the upper valleys very heavy showers accompany the nor-wester, the snow melts, and the rivers which rise in the glaciers and upper valleys are very suddenly freshed, rising from 10 to 20 feet in a night. This wind frequently dies away at night, and begins again before mid-day.

"On the plains the rainfall is small, probably less than 30 inches. On the western slope of the backbone range, the climate is very wet.

"This nor-west wind blows continually all through the summer, and is stronger than any wind I have ever felt—in the river-beds dust and pebbles are blown along furiously, and even on the grassy plains it is often barely possible to ride against the storm. When you attempt to speak, your words appear to be blown down your throat again; and after a day spent battling with this storm, one feels bruised, battered, and exhausted.

"The wind in its greatest fury does not reach entirely across the plain, and is often confined to the lower front ranges, and some few miles to the east.

"I had on one occasion to harvest (working for a week) a field of corn by moonlight, being entirely prevented from working by day by this wind.

"Yours, dear Sir,

"MURROUGH O'BRIEN."

In Fig. 14, I show the actual mean vertical and horizontal motions of the atmosphere, caused by the irregular distribution of land and water in the northern hemisphere.

If there existed no water on the surface of the earth,

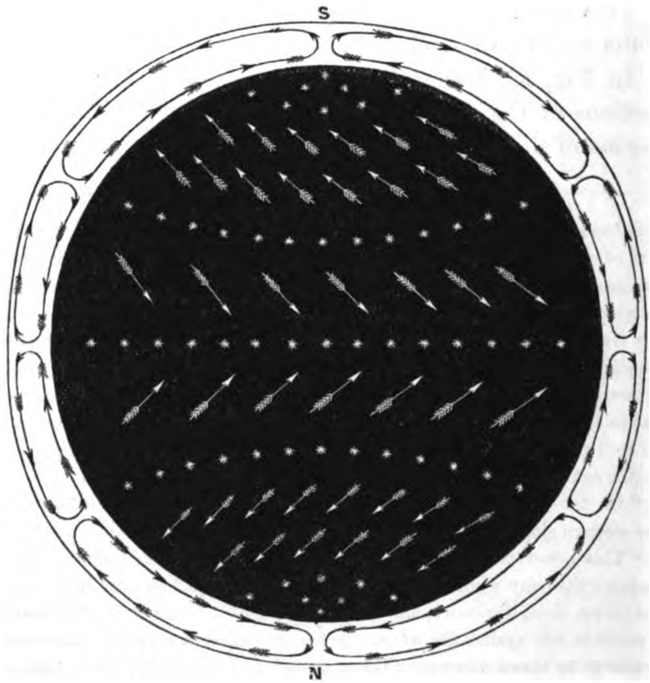

Fig. 13.

the system of winds just described would be very feeble; because it must be remembered that the mere heating of the air at the equator will not disturb the mechanical equilibrium of the atmosphere, which has equal weights whether cold or hot; but the heated dry air at the equator would have a slight tendency to overflow down hill to the north and south, and this displacement would ultimately disturb the mechanical equilibrium and give rise to a system of winds, such as has been described.

The presence of ocean surfaces greatly increases the

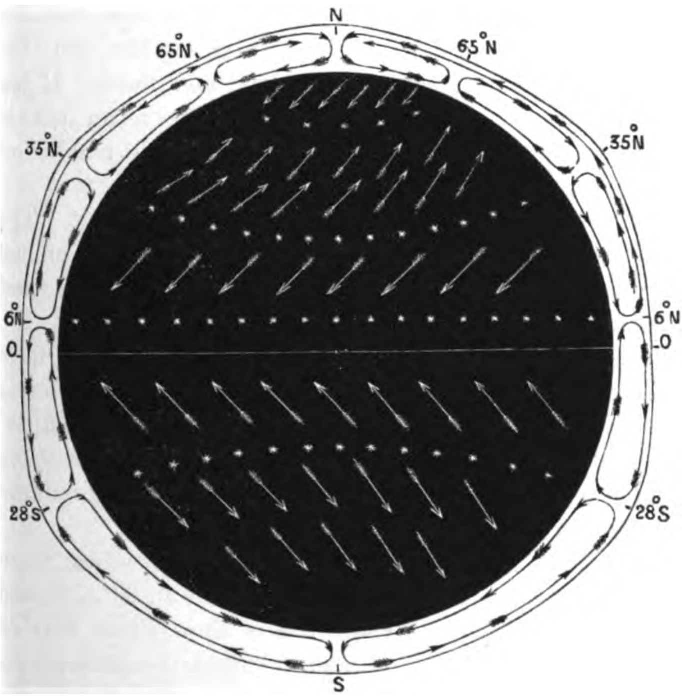

Fig. 14.

force of the winds, for large masses of water are annually evaporated in the tropical regions, and carried by the ascending currents into the upper and colder regions of the air, where they are condensed again as rainfall; and this condensation diminishes the barometrical pressure in the neighbourhood of the Equatorial Calms, and so helps to increase the force of the winds.*

The circulation of the atmosphere, just described, is, indirectly, the chief agent in the distribution of heat and moisture, the two most important elements in the life of plants and animals.

Let us now consider the distribution of heat over the surface of the globe, as depending on the sun, the latitude, and the distribution of land and water. If the surface of the globe were uniform, the mean annual temperature would be constant along each parallel of latitude, and would be a function of the latitude.†

The actual distribution of heat is very different. The following Table (pp. 108–9) shows the mean annual temperature for every ten degrees of latitude and longitude, taken from the most recent authorities.‡

In order to exhibit to the eye the meaning of these figures, I have plotted, in Fig. 15, the variations of mean annual temperature on the parallels of 40°, 50°, and 60° south latitude. These curves show only slight variations from a horizontal line, thus indicating a nearly uniform condition of the earth's surface.

In Fig. 16, I have plotted the corresponding mean annual temperatures of the parallels of 50°, 60°, 70°, and 80° north latitude. These curves show either four or two points of maximum and minimum temperature on the same parallel of latitude, depending altogether on the irregular distribution of land and water in the northern hemisphere.

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* *Vide* Note (C) at end of Lecture.

† *Vide* Note (B) at end of Lecture.

‡ *United States Coast Survey:* Meteorological Researches, part i.—William Ferrel.

Distribution of Heat in the Northern Hemisphere.

Distribution of Heat in the Southern Hemisphere.

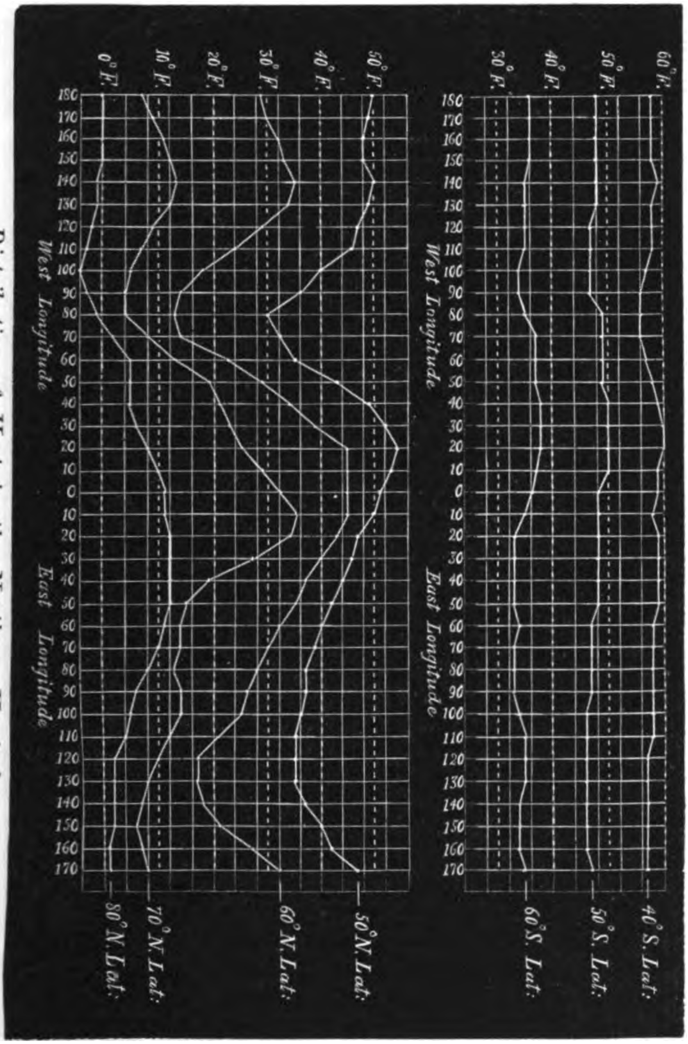

Fig. 16.

Fig. 15.

The horizontal co-ordinates are degrees of longitude. The vertical co-ordinates are degrees Fahrenheit.

Mean Annual Temperature, in Fahrenheit degrees, of the Surface of the Earth.
Longitudes West.

Latitudes.	180°	170°	160°	150°	140°	130°	120°	110°	100°	90°	80°	70°	60°	50°	40°	30°	20°	10°	0°
80° North.	0°	0°	0°	0°	-1°	-1°	-2°	-3°	-4°	-3°	-1°	2°	5°	5°	5°	6°	8°	10°	11°
70 ,,	7	8	9	11	13	12	9	7	5	4	4	8	13	19	21	23	25	29	32
60 ,,	29	30	32	33	35	34	29	24	18	14	13	14	23	29	34	39	45	45	45
50 ,,	50	49	48	48	50	49	47	46	40	36	30	32	35	43	49	52	54	53	51
40 ,,	53	57	57	56	56	57	57	58	60	58	53	52	54	59	62	63	62	62	56
30 ,,	66	64	62	61	61	61	62	67	71	71	69	70	71	72	72	72	71	72	71
20 ,,	76	74	73	72	72	71	71	73	75	82	78	77	78	77	77	78	79	81	82
10 ,,	78	78	78	78	78	78	79	79	79	80	81	81	81	80	80	80	81	83	86
0 ,,	78	78	79	79	79	79	79	80	81	81	82	82	83	82	79	79	79	79	79
10 South.	78	78	78	77	77	77	77	77	77	77	78	79	80	80	79	78	76	76	76
20 ,,	73	73	73	73	73	73	72	72	72	72	72	74	76	77	76	74	72	72	71
30 ,,	67	67	66	66	66	66	65	65	65	64	64	65	67	69	69	69	69	69	66
40 ,,	58	58	58	58	59	58	58	58	57	56	56	56	57	58	59	60	60	59	59
50 ,,	48	48	48	48	48	48	47	47	47	47	49	49	49	49	50	50	50	50	48
60 ,,	36	36	36	36	35	35	35	35	34	34	35	37	37	37	38	38	38	37	36

Mean Annual Temperature, in Fahrenheit degrees, of the Surface of the Earth.
Longitudes East.

Latitudes.	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°	160°	170°	Mean.
80° North.	11°	12°	12°	12°	12°	11°	10°	8°	6°	5°	4°	2°	2°	2°	2°	1°	1°	4°·5 F.
70 ,,	35	34	27	19	15	14	14	13	14	14	12	10	8	7	6	7	8	14·4 ,,
60 ,,	45	43	40	37	35	32	30	28	26	25	21	17	17	18	21	27	32	29·8 ,,
50 ,,	50	47	46	44	42	40	39	37	37	36	35	35	35	37	40	42	47	43·4 ,,
40 ,,	61	61	60	59	57	54	55	56	56	56	53	49	48	50	52	53	54	56·5 ,,
30 ,,	70	70	70	71	71	71	71	70	68	66	64	61	62	64	65	65	65	67·6 ,,
20 ,,	82	83	82	80	78	79	79	80	80	80	79	78	76	77	77	76	76	77·6 ,,
10 ,,	89	90	88	84	83	82	82	82	81	80	80	80	79	79	79	79	78	81·0 ,,
0 ,,	82	87	87	83	81	80	80	80	80	80	80	80	79	78	78	78	78	80·1 ,,
10 South.	82	85	85	82	80	79	79	79	79	79	79	79	79	78	78	78	77	78·7 ,,
20 ,,	76	80	80	79	79	78	77	76	75	75	75	75	75	75	75	75	74	74·7 ,,
30 ,,	68	69	69	69	69	69	69	68	67	67	66	65	64	63	64	65	66	66·7 ,,
40 ,,	58	59	59	59	59	58	58	58	58	58	58	57	57	57	57	57	57	57·9 ,,
50 ,,	48	48	48	48	48	47	47	47	47	46	46	46	46	46	46	46	47	47·8 ,,
60 ,,	35	33	33	33	33	34	33	33	33	34	35	35	35	34	34	34	35	35·8 ,,

In Fig. 17, I have laid down on a Mercator's map the four lines,

AA, CC, of *maximum* mean temperature, for a given latitude; and

BB, DD, of *minimum* mean temperature, for a given latitude.

It will be observed that one *maximum* and one *minimum* curve (AA and BB) are related to the American continents; and one *maximum* and one *minimum* curve (CC and DD) are related to Europasia and Africa.

The American line of maximum temperature, for a given latitude (AA), starts from the mouth of the Mackenzie River, passes through Sitka, and keeps along the north-west coast of North America, until it enters the continent, and occupies a central position on the 40th parallel of north latitude, from which it passes through Nicaragua and Yucatan, into South America, in which it keeps a central position as far as the 20th parallel of south latitude.

The Europasian and African line of maximum temperature (CC) starts from a point to the east of Spitzbergen, and runs south-west, parallel to the coast of Europe, to the 40th parallel of north latitude, where it turns to the south-east, and enters Africa at Teneriffe, and thence becomes central in that continent to the 20th parallel of south latitude.

The general resemblance of the American and Europasian lines of maximum mean annual temperature is well shown on the map, the figures on which, as well as the following Table, prove that the Europasian and African continents enjoy, latitude for latitude, a higher maximum than the American continents.

Lines of Maximum and Minimum Mean Annual Temperature for the same Latitude.

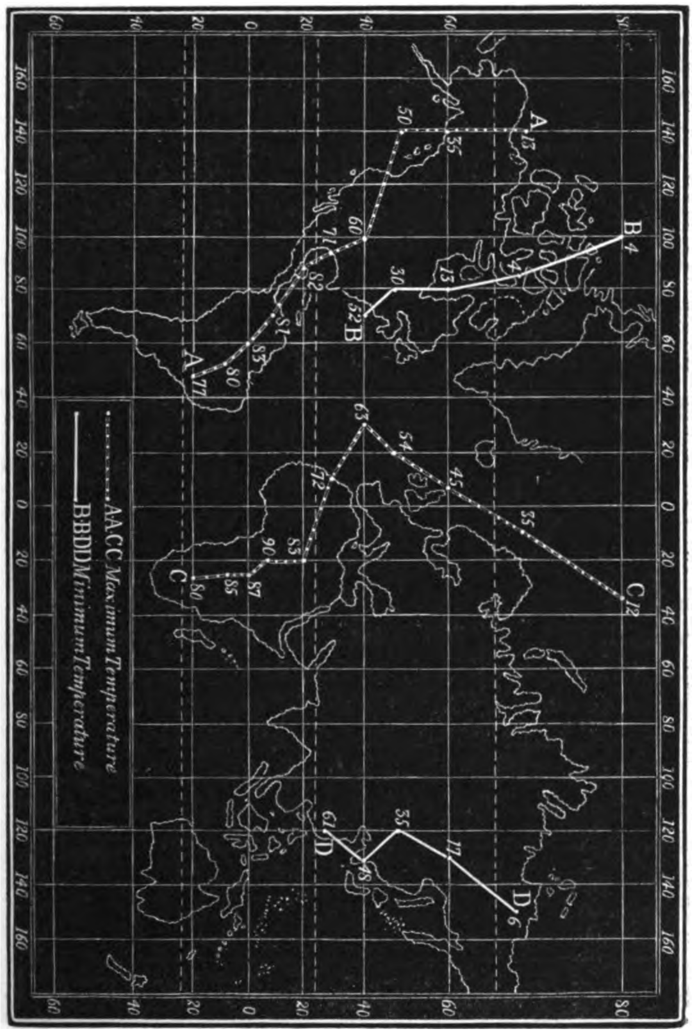

Fig. 17.

Maximum Mean Annual Temperature for a given Latitude.

Latitude.	Europasia and Africa.	The Americas.	Difference.
80° N.	12° Fahr.	—	—
70 ,,	35 ,,	13° Fahr.	+ 22° Fahr.
60 ,,	45 ,,	35 ,,	+ 10 ,,
50 ,,	54 ,,	50 ,,	+ 4 ,,
40 ,,	63 ,,	60 ,,	+ 3 ,,
30 ,,	72 ,,	71 ,,	+ 1 ,,
20 ,,	83 ,,	82 ,,	+ 1 ,,
10 ,,	90 ,,	81 ,,	+ 9 ,,
0 ,,	87 ,,	83 ,,	+ 4 ,,
10 S.	85 ,,	80 ,,	+ 5 ,,
20 ,,	80 ,,	77 ,,	+ 3 ,,

The American line of *minimum* mean annual temperature (BB) starts from the north of the Parry Islands, from thence it passes by North Somerset, Melville Peninsula, and Southampton Island, to the east of Hudson's Bay, thence due south through Canada, and finally reaches New York, on the 40th parallel of north latitude.*

The Europasian line of *minimum* temperature (DD) starts from the Islands of New Siberia (Liakhov), and proceeds through Yakutsk, and the Corea, to Shanghai, on the coast of China, on the 30th parallel of north latitude.

* The lines of *minimum* mean temperature are, approximately, parallel to the east coasts of North America and Asia.

From the preceding facts, we may deduce the following laws of climate :—

Law I. *North of the parallel of* 40° *latitude, the western coasts of Europasia and North America have a* maximum *mean annual temperature, for a given latitude.*

Law II. *North of the parallel of* 40° *latitude, the eastern coasts of Europasia and North America have a* minimum *mean annual temperature, for a given latitude.*

Law III. *Within the Tropics, the central portions of Africa and the Americas have a* maximum *mean annual temperature, for a given latitude.*

Having discussed the laws of distribution of mean annual temperatures, we shall next consider the range of temperatures from summer to winter, which is a subject of as much importance in climates, as the mean annual temperature itself. The following Tables give the range of temperature, from January to July, for every ten degrees of latitude and longitude.

In Fig. 18, I have drawn curves to represent the range of temperature, from January to July, on the 60th parallel of north and south latitude—which will show the enormous difference in the climates of the two hemispheres. In the southern hemisphere, the range, for a given latitude, is nearly constant; but in the northern hemisphere, the range of annual temperature has two maxima and two minima, caused by the continents of Europasia and North America.

In Fig 19, I show, on a Mercator's chart, the four lines AA, BB, CC, DD, of *minimum* and *maximum* range of annual temperature, caused by America and Europasia.

Mean Annual Range of Temperature, from January to July, in Fahrenheit degrees, Longitudes West.

Latitudes.	180°	170°	160°	150°	140°	130°	120°	110°	100°	90°	80°	70°	60°	50°	40°	30°	20°	10°	0°
80° North.	67°	65°	64°	65°	66°	67°	69°	71°	72°	72°	70°	64°	58°	54°	50°	48°	45°	43°	42°
70 ,,	66	64	62	69	74	76	74	74	74	71	68	63	57	47	34	30	26	22	21
60 ,,	38	40	40	42	47	57	67	73	76	76	70	61	46	35	28	22	18	19	22
50 ,,	20	18	16	16	20	26	36	48	60	63	60	55	50	34	22	20	20	22	26
40 ,,	16	17	14	11	8	10	22	32	48	52	46	40	32	22	16	14	16	20	26
30 ,,	12	10	8	9	10	13	16	26	34	34	30	24	18	12	11	12	14	19	21
20 ,,	8	5	6	7	8	9	10	15	18	15	12	11	8	7	6	8	10	14	16
10 ,,	4	4	4	4	4	5	6	6	6	7	6	6	6	6	5	3	2	2	3
0 ,,	4	3	2	2	2	2	2	1	2	1	0	0	2	1	2	2	2	2	2
10 South.	8	8	7	7	5	6	7	6	5	6	5	6	8	9	10	8	4	4	4
20 ,,	10	10	10	10	10	9	8	7	8	9	12	12	12	10	8	8	8	7	6
30 ,,	14	14	13	12	12	12	11	11	10	10	11	14	14	10	10	10	8	5	8
40 ,,	12	13	12	11	10	8	8	9	10	12	12	16	18	18	18	16	12	7	6
50 ,,	7	6	6	6	6	7	8	9	10	11	12	11	11	12	11	10	10	8	7
60 ,,	5	5	5	5	5	6	6	6	6	6	6	7	7	9	8	8	8	8	6

Mean Annual Range of Temperature, from January to July, in Fahrenheit degrees, Longitudes East.

Latitudes.	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°	160°	170°	Mean.
80° North.	43°	44°	44°	44°	43°	42°	44°	47°	53°	58°	63°	68°	70°	72°	71°	70°	68°	59°·1 F.
70 ,,	21	32	43	50	50	48	52	57	64	72	77	84	88	90	89	86	76	59·8 ,,
60 ,,	30	38	47	54	58	64	68	73	77	81	89	95	94	84	74	54	40	55·3 ,,
50 ,,	31	38	44	52	60	68	70	74	74	72	71	70	63	54	45	36	26	44·2 ,,
40 ,,	30	34	36	38	43	48	50	52	52	52	54	58	52	40	32	26	21	33·0 ,,
30 ,,	24	27	31	34	37	38	39	39	41	43	43	42	36	28	23	18	11	24·8 ,,
20 ,,	17	18	20	28	24	22	19	16	15	15	14	15	13	10	9	8	8	18·2 ,,
10 ,,	2	0	4	8	6	4	0	0	2	5	7	7	6	6	6	6	5	4·5 ,,
0 ,,	4	6	6	6	6	4	4	4	2	0	1	0	2	4	4	4	4	2·2 ,,
10 South.	8	10	10	8	7	6	6	6	6	6	6	6	7	8	8	8	9	7·0 ,,
20 ,,	12	12	12	10	9	8	10	12	13	14	14	14	14	14	14	12	11	10·5 ,,
30 ,,	15	18	18	18	18	18	18	16	14	14	14	14	16	18.	16	14	15	13·8 ,,
40 ,,	7	10	10	10	11	12	12	12	12	12	13	14	14	14	12	10	11	11·8 ,,
50 ,,	7	7	6	6	7	8	8	8	9	10	10	10	10	9	9	8	7	8·5 ,,
60 ,,	5	5	5	5	6	6	6	6	6	6	6	6	6	7	7	8	7	6·5 ,,

Mean Annual Range of Temperature on the parallels of 60° S. and 60° N. Latitude.

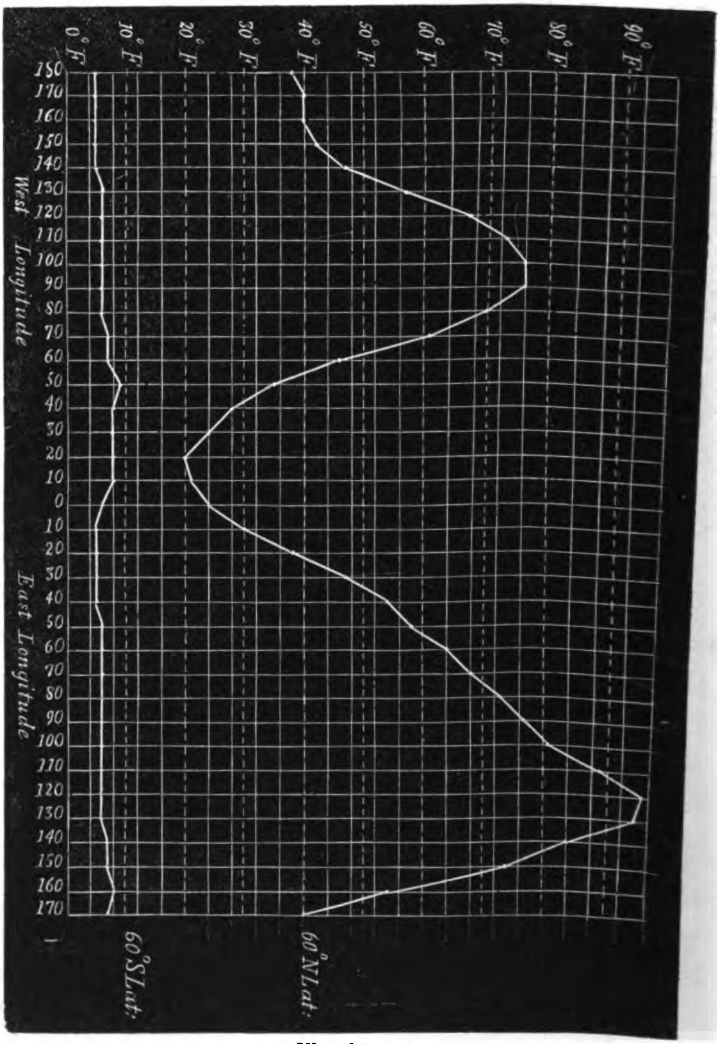

Fig. 18.

The horizontal co-ordinates are degrees of Longitude; the vertical co-ordinates are degrees of Fahrenheit.

Lines of Maximum and Minimum Range of Annual Temperature for the same Latitude.

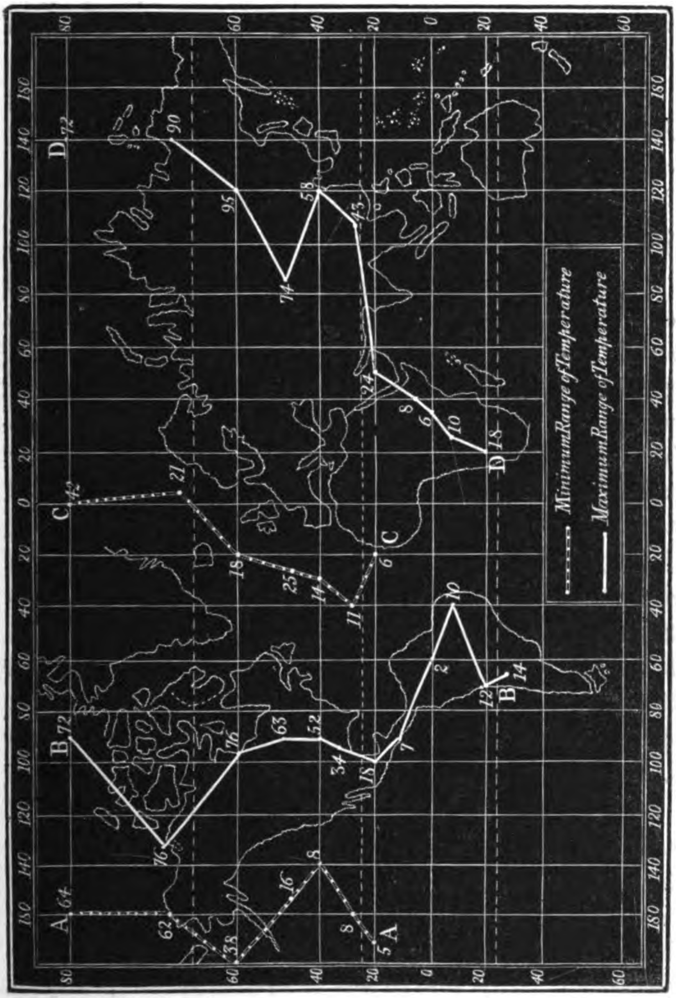

Fig. 19.

(AA). The North American line of *minimum* range of annual temperature passes from the Arctic Ocean, through Behring's Straits, and runs to the southward, keeping in the North Pacific Ocean, to the westward of North America.

(CC). The Europasian line of *minimum* range of annual temperature comes from the Arctic Ocean, east of Greenland, and runs down the North Atlantic, passing between Iceland and Norway, and keeping to the westward of Europe and Africa.

The term "Insular Climate" has been always given to climates in which the annual range of temperature is small, because it has been observed that the presence of the ocean diminishes the heat of summer and the cold of winter, and so reduces the annual range of temperature. The propriety of the term is shown by the pertinacity with which the lines AA and CC cling to the water and avoid the land.

(BB). The North American line of *maximum* range of annual temperature is observed to keep inside the continents of North and South America, avoiding the sea on both sides; it is curious also to notice, that it enters South America through the narrow isthmus of Central America, and refuses to cross the Gulf of Mexico or the Caribbean Sea.

(DD). The Europasian line of *maximum* range of annual temperature enters Asia through the Liakhov Islands, and runs in a south-westerly direction to China, from which it changes its course and runs across Upper India, into Arabia, and Africa, where it turns again to the south-west. This line avoids the ocean as completely as its American companion.

The term "Continental Climate" has been always given to a climate in which there was a great range of temperature from summer to winter, and the map shows the propriety of the term.

It will be seen from the figures on the chart, or from the following Table, that the *maximum* ranges of temperatures caused by Europasia and Africa exceed, latitude for latitude, the *maximum* ranges of temperature produced by the Americas.

Maximum Range of Annual Temperature for a given Latitude.

Latitude.	Europasia and Africa.	The Americas.	Difference.
80° N.	72° Fahr.	72° Fahr.	0° Fahr.
70 ,,	90 ,,	76 ,,	+ 14 ,,
60 ,,	95 ,,	76 ,,	+ 19 ,,
50 ,,	74 ,,	63 ,,	+ 11 ,,
40 ,,	58 ,,	52 ,,	+ 6 ,,
30 ,,	43 ,,	34 ,,	+ 9 ,,
20 ,,	24 ,,	18 ,,	+ 6 ,,
10 ,,	8 ,,	7 ,,	+ 1 ,,
0 ,,	6 ,,	2 ,,	+ 4 ,,
10 S.	10 ,,	10 ,,	0 ,,
20 ,,	18 ,,	12 ,,	+ 6 ,,
30 ,,	—	14 ,,	+ 4 ,,

It has been already shown, pp. 110–112, that the effect of Europasia and Africa in raising the mean annual temperatures is greater than the effect of the Americas. This result, and that shown in the present Table, are to be expected from the greater magnitude of the Old Continents.

If we compare Figs. 17 and 19, we shall see that there is a fair general agreement in the northern hemisphere in the lines AA, BB, CC, DD. From all the facts stated, we may deduce the following additional laws of climate :—

Law IV. *In the northern hemisphere, the places which enjoy a* maximum *mean annual temperature have also a* minimum *range of annual temperature ;* i. e., *they have an Insular climate.*

Law V. *In the northern hemisphere, the places which possess a* minimum *mean annual temperature have also a* maximum *range of annual temperature;* i. e., *they have a Continental climate.*

Law VI. *Large masses of* land, *anywhere,* increase *the range of annual temperature; and large masses of* water, *anywhere,* diminish *the range of annual temperature.*

The causes that produce the laws of climate are the following :—

1. The transfer of heat from lower to higher latitudes, by means of aqueous vapour carried by the atmospheric circulation.

2. The transfer of heat from the tropics to the temperate zones by means of the oceanic circulation.

3. The different heat absorbing and heat radiating properties of land and water.

1. **The transfer of heat from lower to higher latitudes, by means of aqueous vapour carried by the atmospheric circulation.**—If the evaporation in the torrid zone exceeds the rainfall in that zone, the excess must be carried, by the agency of the antitrade winds (*vide* Figs. 13, 14), into the temperate zones, and there precipitated as rain, transferring to those zones all the latent heat of the aqueous vapour that produced that rain. On the contrary, if the rainfall of the torrid zone is equal to the evaporation, all the heat will remain in that zone, and the atmospheric circulation will not benefit the climates of the temperate zones by transferring heat from the torrid zone.

The following estimates of tropical rainfall and evaporation show that the latter alternative is correct, and that Mr. Croll* is justified in stating that the greatest part of the vapour carried by the winds in the temperate zones is raised from the sea within those zones, and that little, if any, comes from the torrid zone.

Mr. Robert H. Scott, Secretary of the Meteorological Department, has kindly furnished me with the latest returns of rainfall between 35° N. and 28° S. latitude.† From these returns I have calculated, from 110 Continental stations, the

Mean Tropical Continental‡ Rainfall, = **67·67** inches.

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* *Climate and Time*, p. 29 (London, 1875).

† *Vide* Note (A) at end of Lecture.

‡ This result was obtained by multiplying the average rainfall at each station by the number of years of observation, adding all the products together, and dividing the sum by the total number of years. This method gives a more probable result than the Arithmetical Mean, which is **70·34** inches—but 67·67 inches $= \frac{7008880}{103575}$.

We obtain a somewhat different result when we examine the insular stations within the tropics. These results are contained in the following Table:—

Insular Rainfall in the Tropics.

Station.	Years of Observation.	Annual Rainfall.	Product.
		Inches.	
1. Isle Bourbon, ...	6	79·2	475·2
2. Mauritius, ...	19	42·7	811·3
3. St. Helena, ...	4	18·8	75·2
4. Jamaica, ...	26	36·0	936·0
5. Bahamas, ...	2	52·0	104·0
6. Havannah, ...	7	91·4	639·8
7. Guadaloupe, ...	6	95·0	570·0
8. St. Vincent, ...	6	78·2	469·2
9. Antigua, ...	5	47·9	239·5
10. Barbadoes, ...	25	57·7	1442·5
11. Funchal, ...	9	28·0	252·0
12. Key West, ...	11	37·7	414·7
13. Port au Prince, . . .	5	62·1	310·5
14. Port Blair, ...	7	116·1	812·7
15. Java, ...	13	147·7	1920·1
16. Ascension, ...	2	3·3	6·6
17. Otaheite, ...	5	47·7	238·5
Total, ...	158	—	9717·8

$$\text{Mean of all} = \frac{9717{\cdot}8}{158} = 61{\cdot}50 \text{ inches per annum.}$$

There can be no doubt that the insular constant is nearer to the true mean than the Continental constant—

when we remember that three-fourths of the area of the torrid zone is water, and that the rainfall in the interior of the continents is less than near their coasts, where most of the observations were made.

We have very little direct information respecting the annual evaporation from a water surface in the tropics, notwithstanding that such knowledge would be of vast importance in questions relating to the storage of water in tanks for the purpose of irrigation.

Observations made for me at St. Helena,* in 1862–3–4, by Major Phillips, R.A., and Lieut. Haughton, R.A., show, in that locality, a very regular annual evaporation, the mean of which is 83·78 inches.

Annual Evaporation of Water Surface at St. Helena.

1862,	. . . .	85·95† inches.
1863,	. . . .	84·48 „
1864,	. . . .	80·90 „
Mean,	. . .	**83·78** inches.

We may calculate from this annual evaporation at St. Helena, Lat. 17° S., the mean annual evaporation of the whole torrid zone, on the supposition that the mean annual evaporation, within the tropics, varies as the cosine of the latitude.‡

* *Proceedings Royal Irish Academy*, June 27, 1864.

† This figure is estimated from four months' observations, by a multiplier taken from the two other years—which was 3·35 for 1863, and 3·41 for 1864.

‡ This supposition is based upon the fact, that the total annual heat received by a given surface, within the tropics, varies very nearly as the cosine of the latitude, although, for places outside the tropics, it varies in a much more complex manner. This question will be discussed in the Note (B) appended to this Lecture.

This gives us—

$$e = a \cos \lambda;$$

where e is the mean annual evaporation at the latitude λ, and a is the mean annual evaporation at the equator.

Substituting for e and λ, their values at St. Helena, we find—

a = mean annual evaporation at equator or = 87·607 inches.

To find the mean annual evaporation of any belt bounded by the equator and a parallel of latitude λ, we have

$$\frac{a\int_0^\lambda \cos\lambda\, d\lambda}{\lambda}, \text{ or } \frac{a \sin \lambda}{\lambda}.$$

Substituting

$$a = 87{\cdot}607,$$
$$\lambda = 23^\circ\, 28',$$

we find—

$$\left.\begin{array}{l}\text{Mean annual evaporation}\\ \quad\text{of whole torrid zone}\end{array}\right\} = \frac{87{\cdot}607 \times \sin 23^\circ 28' \times 180}{23{\cdot}5\,\pi}$$

$$= 85{\cdot}057 \text{ inches.}$$

As one-fourth of the surface of the torrid zone is land, and only three-fourths water, we must reduce the vaporised water capable of producing rain, by one-fourth; which gives us finally,

$$\left.\begin{array}{l}\text{Rainfall in torrid zone}\\ \quad\text{produced by the water}\\ \quad\text{vaporised in the same}\\ \quad\text{zone,}\end{array}\right\} = \mathbf{63{\cdot}79} \text{ inches per annum.}$$

On comparing this calculated result with the insular observed constant, viz., 61·50 inches, we find a close agreement. From this it follows :—

1. That Mr. Croll's statement is probably correct, that the temperate zones owe very little of their heat to the latent heat of vapour formed in the torrid zone.

2. That the mean annual rainfall of the tropics is greatly exaggerated when estimated at 100 inches, because there does not appear to be evaporation sufficient to produce anything like that amount*.

---

* The following estimates of the annual evaporation of a water surface in the tropics have been obtained by the study of the tanks, or reservoirs, of India. Mr. Binnie* estimates the evaporation per day, of the Ambájharí Reservoirs, Nágpúr, Lat. 29° 9′ N., at 0·0167 ft. during the dry season. This coefficient gives for the whole year a maximum evaporation equal to 73·15 inches. My own St. Helena constant, reduced to the latitude of Nágpúr, would be 81·7 inches.

Mr. Russel Aitken* estimates the evaporation per annum of the Vehar Lake, near Bombay, Lat. 18° N., with an area of two square miles, at only 42 inches. In fact, he states that evaporation and leakage, added together, amount to only 60 inches.

Observations on evaporation were made at the Madras Observatory, for 13 years, from 1830 to 1843, by Mr. T. G. Taylor, by means of a cylindrical copper vessel, freely exposed to the sky. The mean daily evaporation was found to be:—

January, . . .	0·300 inch.	July, . . .	0·413 inch.
February, . .	0·305 ,,	August, . .	0·354 ,,
March, . . .	0·359 ,,	September, .	0·334 ,,
April, . . .	0·392 ,,	October, . .	0·288 ,,
May, . . .	0·460 ,,	November, .	0·247 ,,
June, . . .	0·484 ,,	December, . .	0·266 ,,

Mean, ... 0·350 inch.

This gives a total in the year of 127·75 inches.

Lieutenant Ludlow found, by comparative experiments on the edge of the Red Hill tank, with a vessel similar to the above, and also on the surface of the tank, that the ratio of the evaporation from the latter was, to that on the former, as 10 to 14. This would give an annual evaporation at Madras of 91·25 inches.

The experiments made for me at St. Helena were made in a glass vessel, placed in a much larger wooden vessel, filled with water up to the water level inside the glass; as my object was to make the water surface experimented on a portion of a much larger water surface.

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* *Proceedings of Institution of Civil Engineers*: vol. xxxix. (1875).

The reason why the vapour formed in the torrid zone is also condensed there is seen from Figs. 13, 14, which show that at the belt of equatorial calms, formed by the meeting of the north-east and south-east trades, the vapour formed is carried by the upward component into the higher regions of the air, from which it flows to the northward and southward, in upper currents south-westerly and north-westerly in the two hemispheres. Between the parallels 35° N. and 65° N., the south-westerly antitrades carry annually great quantities of vapour raised on the surface of the ocean in more southern latitudes, which vapour, being precipitated as rain, gives out its latent heat to the more northern soil on which it falls. This rainfall on the western coasts of North America and Europasia is one of the chief causes of the Climate Laws (I. and IV.), and explains the high mean annual temperature and insular climates of those coasts.

The Climate Laws (II. and V.) are also occasioned by the absence of this rainfall on the eastern coasts of North America and Europasia; for the south-west antitrades arrive, quite deprived of moisture, at the eastern coasts.

The importance of the rainfall in conveying heat to higher latitudes may be estimated from the fact that

One gallon of rainfall gives out latent heat sufficient to melt 75 *pounds of ice, or to melt* 45 *lbs. of cast iron.**

---

* The following Table shows the exact amount of latent heat contained in vapour at various temperatures :—

Quantity of Heat in Vapour, estimated by the quantity of Ice melted by a gallon of rainfall.

Temperature.	Pounds of Ice melted.	Temperature.	Pounds of Ice melted.
40° Fahr.	76·15 lbs.	60° Fahr.	75·16 lbs.
45 ,,	75·91 ,,	65 ,,	74·94 ,,
50 ,,	75·65 ,,	70 ,,	74·69 ,,
55 ,,	75·43 ,,	75 ,,	74·44 ,,

From this *datum* it is easy to see that every inch of rainfall is capable of melting a layer of ice upwards of eight inches in thickness spread over the ground.*

In order to understand fully the benefit conferred by rainfall, it is desirable to have an estimate of the annual heat received from the sun on each parallel of latitude. This may be found as follows.

It appears from the experiments of Sir John Herschell and M. Pouillet, allowing for absorption of heat by the atmosphere, that a square foot, at the equator, would receive from the sun placed in the zenith, 64·74 ft. lbs. per second.† This would amount to 2,798,768 ft. lbs. in twelve hours, if the sun remained stationary in the zenith for that time. The total quantity of heat received by a square foot at the equator on the day of the equinox is,

$$\frac{64{\cdot}74 \times 43200}{\pi}\int_{-90}^{+90} \cos z \, dz$$

$$= \frac{64{\cdot}74 \times 43200 \times 2}{\pi} = 1{,}780{,}477 \text{ ft. lbs.}$$

where

z = sun's zenith distance.
π = ratio of circumference to diameter in circle.
43200 = length of daylight in seconds.

From this *datum* we can calculate the total annual heat received at any place within the tropics, assuming that it varies as the cosine of the latitude simply.

Total annual heat received, per square foot, within the tropics, expressed in terms of the thickness of ice standing on the square foot, which would be melted,

$$= 2A \cos \lambda,$$

* Exactly 8·1698 inches.

† Croll—*Climate and Time*, p. 26.

where

$$2A^{*} = \frac{365 \cdot 25 \times 1{,}780{,}477 \times 0 \cdot 9591}{772 \times 62 \cdot 5 \times 144 \times 0 \cdot 918} = \left\{ \begin{array}{l} 97 \cdot 79 \text{ feet of ice} \\ \text{melted at the} \\ \text{equator.} \end{array} \right.$$

We may show the importance of rainfall as an element of climate by the example of Ireland. The west coast of Ireland enjoys a rainfall of 45 inches per annum, and its mean latitude is 52°·30 N. Let us now compare the amount of heat given by the sun annually to this coast directly, with the amount also given by the sun indirectly by means of rainfall:—

$$\left. \begin{array}{r} \text{Direct heat } (\textit{vide} \text{ Table in} \\ \text{Note (B) at end of Lecture)} \end{array} \right\} = \left\{ \begin{array}{l} 61 \cdot 4 \text{ feet of} \\ \text{ice melted.} \end{array} \right.$$

$$\left. \begin{array}{r} \text{Indirect heat} \\ \text{(Rainfall)} \end{array} \right\} = \frac{45 \times 8}{12} = \left\{ \begin{array}{l} 30 \cdot 00 \text{ feet of} \\ \text{ice melted.} \end{array} \right.$$

From this it appears that the indirect heat contributed by the rainfall and atmospheric circulation is nearly half that contributed by the direct influence of the sun.

The accompanying map,† Fig. 20, shows the districts on the earth's surface where the mean annual rainfall exceeds 47·2 inches (1200 millimetres). It will be seen from this map, that the areas of large annual rainfall are connected, either with tropical regions, or with mountain ranges which serve as condensers for the aqueous vapour carried by the prevailing winds.

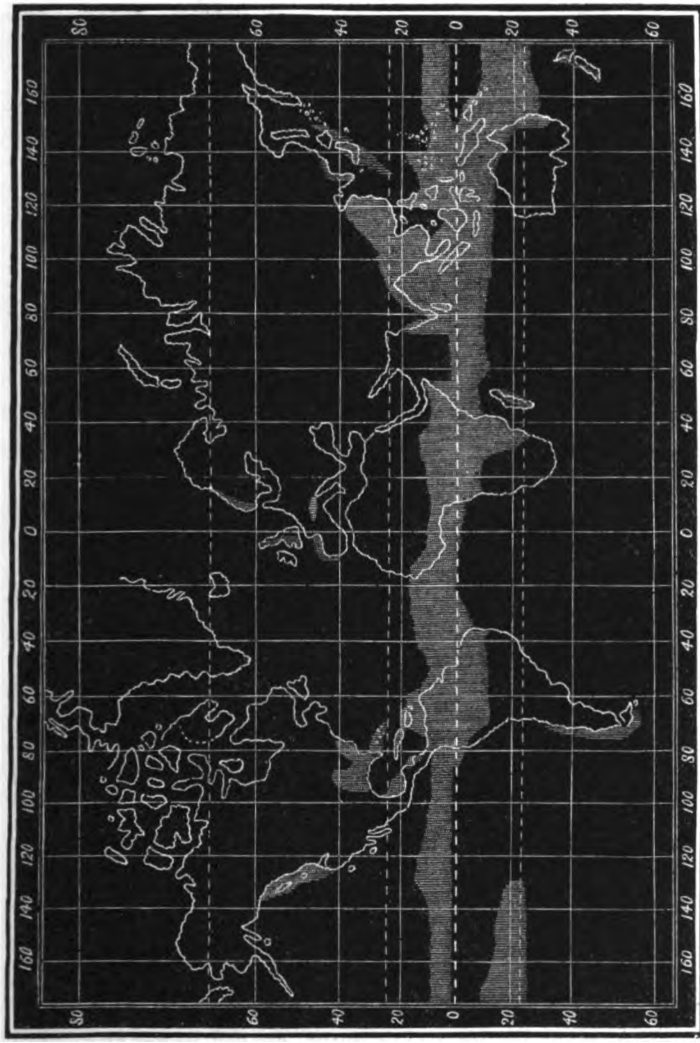
---

* In this formula:—

365·25 = number of days in year.
772 = foot pounds necessary to raise one pound of water through one degree.
62·5 = number of pounds in cubic foot of water.
144 = latent heat of ice.
0·918 = specific gravity of ice.
0·9591 = correction for sun's declination.‡

† Copied from A. Wojeikof, in Petermann's *Mittheilungen*: 1874.

‡ *Vide* Note (B) at end of Lecture.



The shaded portions of the Map represent mean annual rainfalls, exceeding 47 inches.

Fig. 20.

2. **The transfer of heat from the Tropics to the Temperate Zone by means of the Oceanic Circulation.**—The system of oceanic circulation is the direct consequence of atmospheric circulation. The whole surface of the ocean within the tropics is impelled slowly westwards by the trade winds, which would cause a continuous westerly stream, filling the entire width of the tropics, if there were no land surfaces to stop it. This broad westerly equatorial stream is interrupted by land, in three places, viz. :—

By The east coasts of North and South America,
„ The East Indian Archipelago,
„ The east coasts of Africa:

this interruption of the equatorial stream, giving rise to three systems of circulation by which the warm waters of the tropics are carried, bodily, into the temperate zone.

The Oceanic Circulation of the Atlantic Ocean.—The equilibrium belt of equatorial calms lies at 6° N. Lat. (*vide* Fig. 14), north and south of which parallel of latitude two broad surface streams of water, driven by the trade winds, flow to the westward, forming the north and south equatorial currents.

The whole of the north equatorial current is stopped in its westward movement by the American continent, and forced to flow to the northward and eastward. It therefore forms, in the manner described at p. 101, the nucleus of a circulatory current revolving to the *right* in the North Atlantic Ocean.

The south equatorial current strikes upon Cape St. Roque, in South America, and is there divided into two streams, one moving to the north-west into the Caribbean

Sea and Gulf of Mexico, ultimately joining the modified north equatorial current, and aiding to form the circulating current revolving to the right in the North Atlantic Ocean. The other portion of the south equatorial current runs to the south along the coast of Brazil, and, being in the southern hemisphere,* tends to alter its direction towards the left hand, and ultimately gives rise to the circulatory current revolving to the *left* in the South Atlantic Ocean.

It will be noticed that the North Atlantic receives warm water not only from the northern tropics, but also a large portion of the warm water of the southern tropics. In the interior of the circulatory current of the North Atlantic Ocean is found the celebrated Sargasso† sea, forming a floating island of an elongated oval form, between the 25th and 65th degrees of west longitude, and the 18th and 28th of north latitude, affording a home to myriads of molluscs and crustaceans.

The Oceanic Circulation of the Pacific Ocean.—When we proceed to the westward, to the Pacific Ocean, we find a perfectly similar system of ocean currents established by the joint action of the trade winds and the rotation of the earth, viz., a broad equatorial current setting to the westward, from America to the Indian Archipelago and Australia; where, being interrupted by the land and islands, it is diverted to the north and south, in the North and South Pacific Oceans, and converted, as in the Atlantic Ocean, into a right-handed circulatory current in the North Pacific, and into a left-handed circulatory

* *Vide* page 101.

† The rootless seaweed known as Gulfweed (*Sargassum bacciferum*).

current in the South Pacific. A great Sargasso sea occurs also in the centre of the circulation of the North Pacific Ocean, and occupies from the 30th to the 40th parallel of latitude.

The Oceanic Circulation of the Indian Ocean.—In the South Indian Ocean, the trade winds and rotation of the earth produce a great left-handed system of circulation, containing in its centre a Sargasso sea, similar to those of the North Atlantic and North Pacific Oceans.

In the North Indian Ocean, the limited size of the ocean, and the interference of the Monsoons* with the regular trade winds, prevent the development of the usual right-handed circulation.

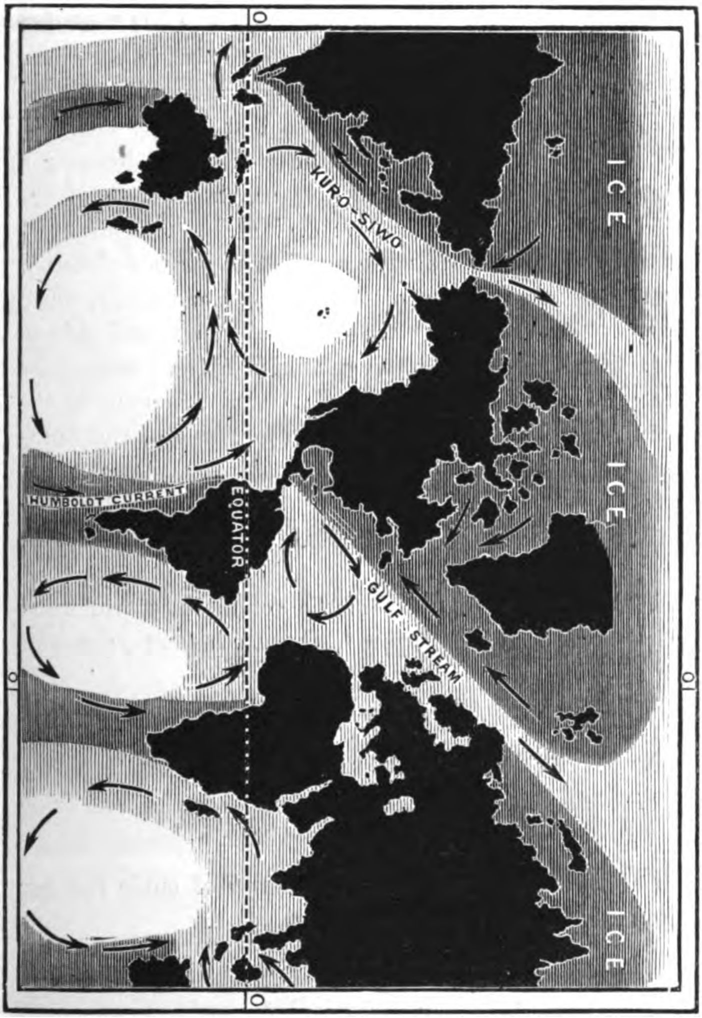
The map, Fig. 21, gives a general view of the five systems of oceanic circulation, two in the northern hemisphere (right-handed), and three in the southern hemisphere (left-handed), by means of which the warm water of the tropics is carried into the temperate zones.

These currents of warm water, on leaving the tropics, may be regarded as great ocean rivers, flowing, without mixing, freely over their water-beds, and carrying their momentum, modified by the earth's rotation, far into the higher latitudes of the temperate zone. The best known of these ocean rivers of warm water are:—

The Gulf Stream (North Atlantic).
The Kuro-Siwo† (North Pacific).
The Mozambique Current (South Indian).
The Brazilian Current (South Atlantic).

* These are described in my next Lecture.

† The *Black Stream*, so called by the Japanese from the deep blue colour which distinguishes it from the surrounding water. This deep blue colour is also a characteristic of the Gulf Stream.



***Oceanic Circulation.*—The warm water currents are lightly shaded, and the cold water currents are darkly shaded.**

Fig. 21.

The Gulf Stream.—The Gulf Stream (of warm water) is shown in the accompanying map, Fig. 22,* issuing from the Straits of Florida, in Lat. 25° N., in a narrow stream; as it moves to the northward and eastward, the width of the stream increases, until at 47° N. Lat. and 25° W. Long., it has a width of 800 miles—forming a vast sheet of warm water lying on the surface of the ocean. The Gulf Stream here divides into two branches, shown on the map, viz.: the *south-eastern branch* deflected by the earth's rotation to the south-east and south, which flows southwards along the coasts of Spain and Africa, until it rejoins the north equatorial current caused by the north-east trades, and finally completes again in the Caribbean Sea and Florida the entire circle of the right-handed circulation of the North Atlantic Ocean; the *north-eastern branch* flows to the north and east, along the coasts of Ireland, Scotland, and Norway, between Europe and Iceland, and probably extends beyond Spitzbergen.†

The following estimates of the volume of warm water transferred from the tropics to the north temperate zone have been given by various authorities,—

Maury calls it a stream 32 miles broad, and 1200 feet deep, moving at the rate of five knots per hour.

Sir John Herschell makes it 30 miles broad, and 2200 feet deep, flowing at four miles per hour.

Colding estimates it at 1600 millions of cubic feet per second.

---

* Copied from the admirable chart of Colding.

† There can be no doubt that this portion of the Gulf Stream owes its momentum to the south-west antitrades; while the other portion is produced by the trades and rotation of the earth.

Croll equals it to a stream 50 miles broad, and 1000 feet deep, flowing at the rate of four miles per hour.

The Gulf Stream.—The warm currents have short arrows, and the cold currents have long arrows.

Fig. 22.

*Sir Wyville Thompson** makes it, in May, 1873, sixty miles in width, 100 fathoms deep, and its rate three knots per hour.

* *Voyage of the Challenger:* The Atlantic. Vol. i., p. 371 (Macmillan: London, 1877).

Converting these estimates into a common standard, I find—

Magnitude of Gulf Stream.

Maury, ...	41·89	cubic miles per hour.
Herschell, . .	50·00	" " "
Colding, . . .	39·13	" " "
Croll, ...	37·69	" " "
Thompson, . .	20·45	" " "
Mean, .	**37·834**	cubic miles per hour.

This enormous volume of sea-water leaves the tropics at a temperature not less than 65° F., and is cooled down to at least 40° F. in the temperate zone.

Let us endeavour to calculate what proportion the heat thus transferred from the tropics to the north temperate zone bears to the whole heat received by the tropics from the sun in a year.

We have seen, p. 127, that a square foot at the equator receives 1,780,477 ft. lbs. of heat on the day of the equinox; and we have shown that the Gulf Stream discharges 37·834 cubic miles of water per hour, which give off 25° F. of heat to the north temperate zone. We can calculate from these data the width of a belt at the equator, which receives annually the same amount of heat as is removed from the tropics by the Gulf Stream. The result* of this calculation is, that a belt of 130·62 miles

* Let x be the width of the required belt in miles, then—

$$x = \frac{37{\cdot}834 \times 5280 \times 62{\cdot}5 \times 24 \times 25 \times 772}{\pi \times 7916 \times 1780477}$$

$$= 130{\cdot}62 \text{ miles.}$$

where

37·834 = volume of Gulf Stream in cubic miles per hour.
5280 = number of feet in a mile.
62·5 = weight of cubic foot of water in lbs.

wide at the equator receives an amount of heat equal to that carried away by the Gulf Stream.

This width represents nearly two* degrees of latitude, and as the areas of symmetrical belts at the equator are proportional to the latitudes of their boundary parallels, we have—

Area of equatorial belt equivalent to the Gulf Stream

$$= \text{area of tropics} \times \frac{\sin(1^\circ\, 53'\cdot448)}{\sin(23^\circ\, 28')}$$

$$= \frac{\text{area of tropics}}{12\cdot063}.$$

The equatorial belt just found receives more heat than any other equal area inside the tropics, and hence we conclude that the Gulf Stream carries out of the tropics, into the North Atlantic Ocean, *more than one-twelfth* of the total heat received in the year from the sun by the torrid zone.

The *Kuro-Siwo*, or Japanese warm ocean river, appears to be formed on a much larger scale than the Gulf Stream, as we might expect from the relative dimensions of the North Pacific and North Atlantic Oceans. At its narrowest part, east of the island of Formosa, it has a width of 100 miles, and a velocity of upwards of three

---

24 = number of hours in the day.
25 = degrees of heat lost by Gulf Stream.
772 = Joule's mechanical equivalent of heat.
π = ratio of circumference of a circle to its diameter.
7916 = mean diameter of the earth in miles.
1,780,477 = foot lbs. of heat received, at the equinox, from the sun by a square foot of surface per day.

* $1^\circ\, 53'\cdot448$.

knots per hour, and in all probability carries three times the volume of the Gulf Stream, of warm water, from the tropics into the temperate zone of the North Pacific Ocean.

The *Mozambique Current*, which forms the commencement of the South Indian Ocean currents, is the most important of the three southern systems of ocean circulation. It flows between Africa and Madagascar, and off Cape Corrientes has been observed to have a velocity of nearly six miles per hour, with a volume greater than that of the Gulf Stream.

The *Brazilian Current*, which forms the commencement of the South Atlantic circulation, is much less than the Gulf Stream, because much of the warm water of the south equatorial current crosses the line to join the north equatorial current and aid in forming the Gulf Stream.

We do not know much of the *East Australian Current*, which forms the commencement of the South Pacific circulation; but it must convey a large body of warm water from the tropics, in consequence of the enormous size of the equatorial parts of the Pacific Ocean, which are swept by the trade winds over a space of 12,000 miles, or half way round the globe.

If we call the Gulf Stream unity, we may form an approximate estimate of the other four systems of circulation, as follows:—

1. Gulf Stream, ...	1
2. Kuro-Siwo, ...	2½
3. Mozambique, ...	1½
4. Brazilian, ...	½
5. Australian, ...	1
	6·5

But, I have shown that the Gulf Stream carries from the tropics into the north temperate zone fully one-twelfth part of the heat derived by the torrid zone from the sun. Hence, the five ocean circulations, combined, probably carry off

$$\frac{6 \cdot 5}{12} = 54 \cdot 2 \text{ per cent.},$$

or more than half the solar heat of the torrid zone, and redistribute it in the temperate zones.

Let us return to the Gulf Stream and general system of oceanic currents in the North Atlantic Ocean. The following Table has been constructed from Colding's admirable account of the Gulf Stream, and shows its progress as it expands in the North Atlantic :— *

Progress of the Gulf Stream.

Locality.	Distance from Cape Florida.	Width.	Velocity.	Depth.	Volume.
	miles.	miles.	feet per second.	fathoms.	cubic miles per hour.
1. Cape Florida, . .	0	32	6⅔	250	41·32
2. St. Augustine, . .	280	47	4	300	43·70
3. New York, . . .	1000	127	2½	—	—
4. Newfoundland, .	1800	320	2	166	82·31
5. Point of Bifurcation,	3000	800†	0·6	200	74·38
6. Between Iceland and Scotland, (north-eastern branch)	3800	600	0·3	—	—

* *Extrait d'un Mémoire sur les lois des Courants dans des Conduites ordinaires et dans le Mer :* Copenhagen, 1870.

† The north-eastern and south-eastern branches may be regarded as being here each 400 miles wide, conveying each upwards of 37 cubic miles per hour.

It will be observed, that the Gulf Stream becomes doubled off Newfoundland, and continues its course, with nearly the whole of this double discharge, to the point of bifurcation. On referring to the map, Fig. 22, it will be seen that, while the north-eastern branch of the Gulf Stream flows nearly entirely to the east of Iceland, a counter-current of cold water sets from the north down the east coast of Greenland, and, having reached Cape Farewell, it is turned by the earth's rotation to the right, up Davis' Strait, but again flows back to the southward, united with the important stream from Baffin's Bay. The rotation of the earth keeps the united currents pressed close to the American coast, and bounded on the right by the Gulf Stream. It has been proved by the American observations, that, from Cape Hatteras down to Cape Florida, a system of interlacing of the warm and cold currents takes place, in alternating sheets, and the result is, that the cold current grows less and less, until it is altogether lost in the Gulf Stream, whose volume afterwards becomes doubled from Newfoundland to the Bifurcation.

The motive force which carries this double flow of water towards the north-east is derived from the antitrade winds, which blow from the south-west over the whole course of the Gulf Stream, from Cape Florida to the Bifurcation—a distance of 3000 miles, or one-eighth of the whole circumference of the earth. The cold water current, formed by the union of the East Greenland and Baffin's Bay currents, is estimated, on the coast of Labrador, by Colding as follows:—

Width, ...	200 miles.
Velocity, ...	$\frac{5}{6}$ths of a foot per second.
Depth, ...	250 fathoms.

This gives a discharge of water, to the southward, equal to 32·28 cubic miles per hour—or about *four-fifths* of the discharge of water to the northward by the Gulf Stream at Cape Florida.

In order to complete our view of the ocean circulation in the North Atlantic, we must mention the principle used by mathematicians in Hydrodynamics under the name of the *Equation of Continuity.*

It may be expressed, very simply, by the following self-evident theorem:—

Given a permanent system of constant continuous circulation in any ocean; if any vertical plane be supposed drawn across the ocean, equal quantities of water must cross that plane, from right to left, and from left to right, in a given time; for, if possible, let it not be so, then there will arise a difference of sea level at the two sides of the supposed plane, and the hypothesis of constant continuous circulation will become impossible.

If we take such a vertical plane, from Florida to Portugal, AB, Fig. 22, it will pass through the centre of the Sargasso sea, and the condition of *continuity* will be preserved, because the Gulf Stream at Florida carries from south to north the same quantity of water (viz., 37 cubic miles per hour) that its south-eastern branch carries from north to south off the coast of Portugal.

If we now draw the line CD, from Labrador to Ireland, we find the north-eastern branch of the Gulf Stream carrying 37·19 cubic miles per hour, from south to north, to the westward of Ireland; while the united Labrador current carries only 32·28 cubic miles per hour from north to south.

It is, therefore, mathematically certain that the difference (4·91 cubic miles per hour) must flow southward in the form of submarine currents not observable at the surface.

This balance* of the surface currents will, necessarily, be cold water, and is the chief cause of the very cold water found at all great depths in the North Atlantic Ocean.

3. **The different Heat properties of Land and Water.**—If we contrast a surface of water, in any latitude, with a similar surface of land, we shall see that Law VI. follows at once from the well-known thermal properties of water. The heat absorbed by the land penetrates slowly into the interior of the earth by conduction—raising the temperature by day, and the heat radiated from the land at night lowers the temperature. The difference between the heat absorbed and the heat radiated is the gain or loss of heat for any day. Let—

H = heat absorbed in daytime.
R = heat radiating in 24 hours.
Δ = difference between heat absorbed and heat radiated.

We now have—

$$\Delta = H - R.$$

In our latitudes Δ is positive from January to July, and

* In reality, the residual cold current must be much greater than this, for, in addition to the defect in southerly currents in the North Atlantic, it must compensate for the northerly current entering the Arctic Sea through Behring's Straits, for, in consequence of their shallow depth, there is little, if any, southerly current there.

the sum of all the Δ's is the range of temperature from summer to winter. This sum will be greater for a land surface than for a water surface; for, even supposing that the absorbing and radiating powers of land and water were equal, the water surface will lose heat by evaporation as well as by absorption, and this loss of heat is so important, that (as already stated) the sensible heat rendered latent in the evaporation of one cubic inch of water would suffice to melt eight cubic inches of ice. Hence, Δ for a water surface will become—

$$\Delta = H - R - E,$$

where E is the heat lost by evaporation. Therefore, the sum of the Δ's will be less for a water surface than for a land surface—and therefore the annual range of temperature will be greater for land surfaces than for water surfaces, which is stated in Law VI.

The Climate Law III., which asserts that Africa and South America, within the tropics, contain the points of maximum mean annual temperature, for the same latitude, has for its cause the system of ocean circulation already fully described, in consequence of which the intertropical ocean surfaces, instead of retaining the heat given to them by the sun, convey it into the temperate zones; while the land surfaces of Africa and South America retain the heat absorbed, and so raise their mean annual temperature.

Note A.—Tropical Rainfalls, supplied from the Meteorological Office by Mr. Robert H. Scott, F.R.S., *Secretary*.

Mean Rainfall at Various Continental Stations between 35° N. *and* 28° S. *Latitude.*

Station.	Number of Years.	Height of Station.	Latitude.	Longitude.	Fall of Rain.			
					Under 25 inches.	25–50	50–100	Above 100 inches.
American :—		Feet.						
Huntsville, ...	12	600	34° 36′ N.	86° 57′ W.	—	—	54·9	
Camden, ...	8	275	34 1 ,,	80 33 ,,	—	—	50·6	
Fulton, ...	7	150	33 40 ,,	80 31 ,,	—	—	54·3	
Aiken, ...	6	563	33 32 ,,	81 34 ,,	—	44·5		
St. John's, ...	8	50	33 18 ,,	79 56 ,,	—	43·8		
Sparta, ...	9	550	33 17 ,,	83 9 ,,	—	—	54·1	
Fort Belknap, . . .	5	1600	33 8 ,,	98 48 ,,	—	28·0		
Greensprings, . . .	6	500	32 50 ,,	87 46 ,,	—	48·8		
Charleston, ...	22	—	32 47 ,,	79 57 ,,	—	45·1		
Fort Moultrie, . . .	12	25	32 45 ,,	79 51 ,,	—	44·9		
Greensburgh, . . .	12	—	32 40 ,,	87 40 ,,	—	—	50·4	
Vicksburgh, . . .	14	—	32 23 ,,	90 56 ,,	—	48·9		
Monroe, ...	10	100	32 20 ,,	92 10 ,,	—	—	54·0	
Savannah, ...	23	42	32 5 ,,	81 5 ,,	—	48·3		
Whitmarsh, . . .	11	18	32 3 ,,	81 2 ,,	—	40·3		
Fort Bliss, ...	8	3830	31 47 ,,	106 30 ,,	9·6			
Natchez, ...	8	264	31 34 ,,	91 28 ,,	—	—	58·3	
Fort Jessup, . . .	10	80	31 33 ,,	93 32 ,,	—	45·9		
Monroeville, . . .	5	1[illegible]0	31 33 ,,	87 25 ,,	—	—	60·9	

Mount Vernon, . .	11	200	31 12 ,,	88 2 ,,	—	—	63·5	
Fort McKavett, . .	6	2060	30 55 ,,	100 5 ,,	22·8			
St. Francisville, . .	5	80	30 43 ,,	92 27 ,,	—	—	55·3	
West Feliciana, . .	13	96	30 38 ,,	91 20 ,,	—	—	61·3	
Baton Rouge, . . .	11	41	30 26 ,,	91 18 ,,	—	—	62·1	
Jacksonville, . . .	6	14	30 20 ,,	81 39 ,,	—	—	52·7	
Plaquemine, . . .	6	30	30 20 ,,	91 18 ,,	—	—	67·1	
Austin, ...	9	650	30 19 ,,	97 46 ,,	—	31·1		
Pensacola, ...	9	20	30 18 ,,	78 72 ,,	—	—	57·0	
New Orleans, . . .	17	10	29 58 ,,	90 0 ,,	—	—	51·0	
San Antonio, . . .	6	600	29 25 ,,	98 25 ,,	—	32·9		
Fort Clarke, . . .	8	1000	29 17 ,,	100 25 ,,	22·4			
Inge, ...	5	845	29 9 ,,	99 47 ,,	—	28·0		
Fort Duncan, . . .	6	800	28 42 ,,	100 30 ,,	22·2			
MacIntosh, ...	6	400	27 31 ,,	99 21 ,,	18·7			
Fort Pierce,. . . .	6	30	27 30 ,,	80 20 ,,	—	—	58·0	
Ringgold, ...	6	200	26 36 ,,	99 0 ,,	21·0			
Fort Brown, . . .	9	50	25 53 ,,	97 26 ,,	—	31·5		
Fort Myers, . . .	5	50	26 38 ,,	82 0 ,,	—	—	62·3	
Fort Brooke, . . .	15	20	28 0 ,,	82 28 ,,	—	—	55·5	
Matamoras, ...	9	56	25 52 ,,	97 27 ,,	—	36·7		
Tepic, ...	7	3458	21 22 ,,	104 52 ,,	—	42·9		
Mexico, ...	14	7474	19 25 ,,	99 5 ,,	24·7			
Mirador, ...	8	3035	19 13 ,,	96 50 ,,	—	—	84·7	
Cordoba, ...	9	878	18 51 ,,	96 54 ,,	—	—	—	112·9

Mean Rainfall at Various Stations between 35° N. and 28° S. Latitude.

STATION.	Number of Years.	Height of Station.	Latitude.	Longitude.	FALL OF RAIN. Under 25 inches.	25–50	50–100	Above 100 inches.
INDIAN :—								
Seebsaugor,	11	—			—	—	90·5	
Tezpore,	9	—			—	—	76·1	
Nowgong,	9	—	Assam.		—	—	79·5	
Gowhatty,	9	—			—	—	70·8	
Goalpara,	5	—			—	—	94·4	
Shillong,	4	—	Khasi Hills.		—	—	95·9	
Cherrapunji,	8	—			—	—	—	559·0
Silhet,	11	—			—	—	—	149·8
Cachar,	9	—			—	—	—	123·4
Tipperah,	10	—			—	—	95·9	
Noacally,	12	—			—	—	98·3	
Chittagong,	11	—	Tipperah and Aracan.		—	—	—	108·5
Akyab,	10	—			—	—	—	219·5
Sandoway,	4	—			—	—	—	236·1

Jessore, ...	10	—	Gangetic Delta.	—	—	64·9	
Calcutta, ...	32	—		—	—	66·0	
Krishnagur, . . .	8	—		—	—	60·0	
Moorshedabad, . . .	13	—		—	—	53·1	
Dacca, ...	10	—	Northern Group.	—	—	75·2	
Mymensingh, . . .	6	—		—	—	—	108·0
Begrah, ...	8	—		—	—	91·1	
Rungpore, ...	9	—		—	—	85·2	
Dinagepore,. . . .		—		—	—	85·8	
Maldah, ...	13	—		—	—	51·8	
Rampore, ...	9	—		—	—	63·3	
Moughyr, ...	14	—	Behar	—	39·2		
Gyah, ...	7	—		—	44·3		
Patna, ...	7	—		—	35·7		
Tirhoot, ...	10	—		—	37·1		
Chuprah, ...	13	—		—	34·9		
Arrah, ...	13	—		—	49·2		
Chumparun, . . .	6	—		—	40·0		

Mean Rainfall at Various Stations between 35° N. and 28° S. Latitude.

Station.	Number of Years.	Height of Station.	Latitude.	Longitude.	Fall of Rain. Under 25 inches.	25–50	50–100	Above 100 inches
Indian:—		Feet.						
Bahagulpore,	13	—	Western Group.		—	—	50·9	
Soory,	7	—	Western Group.		—	—	50·0	
Burdwan,	12	—	Western Group.		—	—	61·4	
Banconah,	13	—	Western Group.		—	—	53·3	
Midnapore,	5	—	Western Group.		—	—	64·8	
Manbhoom,	6	—	Western Group.		—	41·0		
Hazareebaugh,	4	—	Western Group.		—	—	50·5	
Ranchee,	13	—	Western Group.		—	41·0		
Balasore,	10	—	Orissa.		—	—	68·5	
Cuttack,	10	—	Orissa.		—	—	53·3	
Pooree,	13	—	Orissa.		—	—	54·8	
Sumbulpore,	6	—	Orissa.		—	47·7		
Darjiling,	8	—	Himalaya.		—	—	—	129·6
Rungbee,	4	5000	Himalaya.		—	—	—	170·5
Poonah,	5	—	18° 29′ N.	73° 53′ E.	23·4			
Mahabuleshwur,	15	4500	18 0 N.	73 30 E.	—	—	—	254·1

Shenkottah, ...	5	600	— N.	— E.	—	39·2		
Palamkottah, . . .	5	200	8 40 N.	77 30 E.	21·1			
Vauriour, ...	5	60	— N.	— E.	24·7			
Madras, ...	32	—	13 5 N.	80 16 E.	—	48·9		
Allepy, ...	5	30	— N.	— E.	—	—	—	113·3
Cochin, ...	5	20	9 58 N.	76 14 E.	—	—	—	106·1
Quilon, ...	5	30	8 54 N.	76 33 E.	—	—	76·8	
Trevandrum, . . .	8½	130	8 29 N.	76 56 E.	—	—	69·4	
Bombay, ...	15	—	18 57 N.	72 51 E.	—	—	71·3	
Anjarra Kandy, . .	14	—	— N.	— E.	—	—	—	123·5
VARIOUS:—								
Georgetown, . . .	7	—	6 50 N.	58 4 W.	—	—	—	100·5
Cayenne, ...	6¾	—	4 56 N.	52 20 W.	—	—	—	138·4
Sierra Leone, . . .	5	250	8 5 N.	13 2 W.	—	—	—	130·2
Goree, Senegal, . .	8	—	16 0 N.	16 30 W.	21·0			
Rio de Janerio, . .	6½	—	22 54 S.	43 20 W.	—	—	53·0	
Brisbane, ...	12	—	27 32 S.	153 2 E.	—	—	50·5	
Alexandria, ...	10	—	31 10 N.	29 55 E.	8·5			
Batavia, ...	5	—	6 22 S.	106 40 E.	—	—	78·2	

Mean Rainfall at Various Insular *Stations between* 35° N. *and* 28° S. *Latitude.*

Station.	Number of Years.	Height of Station.	Latitude.	Longitude.	Fall of Rain. Under 25 inches.	25–50	50–100	Above 100 inches
		Feet.						
St. Vincent, ...	6	—	13° 13′ N.	61° 15′ W.	—	—	78·2	
Antigua, ...	5	—	17 9 N.	61 50 W.	—	47·9		
Havannah, ...	7	—	23 9 N.	82 22 W.	—	—	91·4	
Barbadoes, ...	25	—	13 12 N.	59 35 W.	—	—	57·7	
Funchal, ...	9	—	32 46 N.	16 59 W.	—	28·0		
Key West, ...	11	—	24 34 N.	81 47 W.	—	37·7		
Port au Prince, . . .	—	—	18 37 N.	72 17 W.	—	—	62·1	
Port Blair, ...	7	30	11 41 N.	92 0 E.	—	—	—	116·1
Buitenzoog (Java), . .	13	—	—	—	—	—	—	147·7
Ascension, ...	2	—	7 57 S.	14 28 W.	3·3			
Port Louis (Mauritius), .	19	—	20 18 S.	57 31 E.	—	42·7		
Réunion (Isle Bourbon),	6	—	21 0 S.	55 30 E.	—	—	79·2	
Tahiti, ...	—	—	17 32 S.	149 30 W.	—	47·7		

Note B.—On the Total Annual Heat received at each point of the Earth's Surface from the Sun, and on the Amount of the Loss of that Heat caused by Radiation into Space.

The heat received by a given surface at any instant is

$$A \cos z \, dh,$$

where

$$A = \text{a known constant,}$$
$$z = \text{sun's zenith distance,}$$
$$h = \text{sun's hour angle;}$$

and

$$\textit{Total heat received in one day} = A \int_{\text{Sunset}}^{\text{Sunrise}} \cos z \, dh. \qquad (1)$$

Now, we have

$$\cos z = \sin \lambda \sin \delta + \cos \lambda \cos \delta \cos h,$$

where

$$\lambda = \text{latitude of place,}$$
$$\delta = \text{sun's declination,}$$
$$h = \text{the sun's hour angle, and}$$
$$H = \text{hour of sunset.}$$

Equation (1) thus becomes—

$$\text{Total heat received in one day} = \int_{-H}^{+H} \cos z \, dh$$

$$= \int_{-H}^{+H} A \sin\lambda \sin\delta \, dh + \int_{-H}^{+H} A \cos\lambda \cos\delta \cos h \, dh,$$

$$= 2A \{\sin\lambda \sin\delta \cdot H + \cos\lambda \cos\delta \sin H\}. \qquad (2)$$

But, since

$$\cos H = -\tan\lambda \tan\delta,$$

the expression (2) may be thus written :

$$\text{Total heat received in one day} = 2A \sin\lambda \sin\delta \{H - \tan H\}. \qquad (3)$$

This expression might be expanded by means of Leibnitz' theorem, as follows :

$$\text{Total heat received in one day} = 2A \sin\lambda \sin\delta \left(\frac{\tan^3 H}{3} - \frac{\tan^5 H}{5} + \frac{\tan^7 H}{7} - \&c.\right). \qquad (4)$$

But this would not answer for calculation, as H passes through 90°, at the time of the equinoxes, when $\tan H$ becomes infinite and $\sin\delta$ vanishes. I therefore expand in terms of $\cos H$ as follows :

$$H = \frac{\pi}{2} - \left\{\cos H + \frac{1}{2} \cdot \frac{\cos^3 H}{3} + \frac{1 \cdot 3}{2 \cdot 4} \cdot \frac{\cos^5 H}{5} + \frac{1 \cdot 3 \cdot 5}{2 \cdot 4 \cdot 6} \cdot \frac{\cos^7 H}{7} + \&c. \right\}, \qquad (5)$$

and,

$$\tan H = \frac{\sqrt{1 - \cos^2 H}}{\cos H}$$

$$= \frac{1}{\cos H}\left\{1 - \frac{\cos^2 H}{2} - \frac{1}{1\cdot 2}\cdot\frac{\cos^4 H}{2^2} - \frac{1\cdot 3}{1\cdot 2\cdot 3}\cdot\frac{\cos^6 H}{2^3} - \frac{1\cdot 3\cdot 5}{1\cdot 2\cdot 3\cdot 4}\cdot\frac{\cos^8 H}{2^4} - \&c.\right\}, \qquad (6)$$

Therefore,

$$H - \tan H = \frac{\pi}{2} - \frac{1}{\cos H} - \frac{1}{2}\cos H - \frac{1}{24}\cos^3 H - \frac{1}{80}\cos^5 H - \frac{5}{896}\cos^7 H - \&c.\Big\}. \qquad (7)$$

But,

$$\cos H = -\tan\lambda\tan\delta = -\frac{\tan\lambda\sin\delta}{\sqrt{1 - \sin^2\delta}}$$

$$= -\frac{\sin\lambda\sin\delta}{\cos\lambda}\left\{1 + \frac{\sin^2\delta}{2} + \frac{1\cdot 3}{1\cdot 2}\cdot\frac{\sin^4\delta}{2^2} + \frac{1\cdot 3\cdot 5}{1\cdot 2\cdot 3}\cdot\frac{\sin^6\delta}{2^3} + \frac{1\cdot 3\cdot 5\cdot 7}{1\cdot 2\cdot 3\cdot 4}\cdot\frac{\sin^8\delta}{2^4} + \&c.\right\}, \qquad (8)$$

and

$$\frac{1}{\cos H} = -\frac{\cos\lambda}{\sin\lambda\sin\delta}\left\{1 - \frac{\sin^2\delta}{2} - \frac{1}{1\cdot 2}\cdot\frac{\sin^4\delta}{2^2} - \frac{1\cdot 3}{1\cdot 2\cdot 3}\cdot\frac{\sin^6\delta}{2^3} - \frac{1\cdot 3\cdot 5}{1\cdot 2\cdot 3\cdot 4}\cdot\frac{\sin^8\delta}{2^4} - \&c.\right\}. \qquad (9)$$

Hence, finally,

The heat received in one day $= 2A \sin\lambda \sin\delta \, (H - \tan H)$

$$
= 2A \left.\begin{array}{l}
\frac{\pi}{2} \sin\lambda \sin\delta \\
+ \cos\lambda \left\{ 1 - \frac{\sin^2\delta}{2} - \frac{1}{1\cdot 2} \cdot \frac{\sin^4\delta}{2^2} - \frac{1\cdot 3}{1\cdot 2\cdot 3} \cdot \frac{\sin^6\delta}{2^3} - \&c. \right\} \\
+ \frac{\sin^2\lambda \sin^2\delta}{2\cos\lambda} \left\{ 1 + \frac{\sin^2\delta}{2} + \frac{1\cdot 3}{1\cdot 2} \cdot \frac{\sin^4\delta}{2^2} + \&c. \right\} \\
+ \frac{\sin^4\lambda \sin^4\delta}{24\cos^3\lambda} \left\{ 1 + \frac{3}{2} \sin^2\delta + \&c. \right\} \\
+ \frac{\sin^6\lambda \sin^6\delta}{80\cos^5\lambda} \left\{ 1 + \&c. \right\}
\end{array}\right\} \quad (10)
$$

Or, since

$$\sin\delta = \sin\Delta \sin l,$$

where

$$\Delta = \text{obliquity of ecliptic,}$$

$$
= 2A \left|
\begin{array}{l}
\frac{\pi}{2} \sin\lambda \sin\Delta \cdot \sin l \\
+ \cos\lambda \left\{ 1 - \frac{\sin^2\Delta}{4}(1 - \cos 2l) - \frac{\sin^4\Delta}{64}(3 - 4\cos 2l + \cos 4l) - \frac{\sin^6\Delta}{512}(10 - 15\cos 2l + 6\cos 4l - \cos 6l) - \&c. \right\} \\
+ \tan\lambda \sin\lambda \left\{ \frac{\sin^2\Delta}{4}(1 - \cos 2l) + \frac{\sin^4\Delta}{32}(3 - 4\cos 2l + \cos 4l) + \frac{3\sin^6\Delta}{512}(10 - 4\cos 2l + 6\cos 4l - \cos 6l) + \&c. \right\} \\
+ \tan^3\lambda \sin\lambda \left\{ \frac{\sin^4\Delta}{192}(3 - 4\cos 2l + \cos 4l) + \frac{\sin^6\Delta}{512}(10 - \&c.) + \&c. \right\} \\
+ \tan^5\lambda \sin\lambda \left\{ \frac{\sin^6\Delta}{2560}(10 - \&c.) + \&c. \right\} \\
+ \&c.
\end{array}
\right\} \quad (11)
$$

We must now substitute for l the sun's longitude, on each day of the year, and add the 365 terms together; this will convert all the periodic terms of (11) into the sums of sines and cosines of arcs in arithmetical progression taken all round the circumference, and with a very small common difference.*

* Equal to 59′ 8″ (the daily change in sun's longitude), or small multiples of that arc.

The periodic terms, therefore, vanish in the summation, and we obtain—

The heat received in one year $= 2A \sin\lambda\, \Sigma \sin\delta\, (H - \tan H)$

$$= 2A \times 365{\cdot}25 \left| \begin{array}{l} \cos\lambda \left\{1 - \dfrac{\sin^2\Delta}{4} - \dfrac{3\sin^4\Delta}{64} - \dfrac{5\sin^6\Delta}{256} - \&c.\right\} \\ + \tan\lambda \sin\lambda \left\{\dfrac{\sin^2\Delta}{4} + \dfrac{3\sin^4\Delta}{32} + \dfrac{15\sin^6\Delta}{256} + \&c.\right\} \\ + \tan^3\lambda \sin\lambda \left\{\dfrac{\sin^4\Delta}{64} + \dfrac{5\sin^6\Delta}{256} + \&c.\right\} \\ + \tan^5\lambda \sin\lambda \left\{\dfrac{\sin^6\Delta}{256} + \&c.\right\} \\ + \&c., \&c. \end{array} \right\} \quad (12)$$

Substituting for Δ its value, 23° 28′, we obtain, finally,

$$= 2A \times 365{\cdot}25 \left| \begin{array}{l} 0{\cdot}95910 \cos\lambda \\ \quad + 0{\cdot}04187 \tan\lambda \sin\lambda \\ \qquad + 0{\cdot}00047 \tan^3\lambda \sin\lambda \\ \qquad\quad + 0{\cdot}000015 \tan^5\lambda \sin\lambda \\ \qquad\qquad + \&c. \end{array} \right\} \quad (13)$$

It is evident, from this equation, that when the latitude is small, the heat received in the year varies as the cosine of the latitude, as stated in p. 123.

It is to be observed that equation (3), which expresses the heat received in one day, becomes illusory inside the Arctic and Antarctic Circles, when the sun does not set; for then H (the hour of sunset) has an imaginary value. We must, therefore, compute the annual heat received inside these circles by summing the heat from the equinox till the time when the sun does not set or does not rise, by equation (12); and adding the heat received during the time when the sun does not set.

If D denote the sun's declination, when he ceases to rise or set, equation (12), with D substituted for Δ, will give the heat received during the part of the year when the sun rises and sets, and the angle H is real.

To this must be added the heat received during the time when the sun never sets, which may be found as follows:

Referring to equations (1) and (2), we have, when the sun does not set,

$$\textit{Total heat in one day} = A\int_0^{2\pi} \cos z \, dh \qquad (14)$$

$$= A\int_0^{2\pi} \sin\lambda \sin\delta \, dh + A\int_0^{2\pi} \cos\lambda \cos\delta \cos h \, dh,$$

$$= 2A\pi \sin\lambda \sin\delta = 2A\pi \sin\lambda \sin\Delta \sin l.$$

This value must be summed through the time that the sun does not set; or, if a be the daily change in sun's longitude,

$$\left.\begin{array}{r}\text{The total heat received}\\ \text{during the time that}\\ \text{the sun never sets}\end{array}\right\} = 2A\pi \sin\lambda \sin\Delta \{\sin l + \sin(l+a) + \sin(l+2a)\} + \&c. \qquad (15)$$

$$= 2A \cdot \pi \sin\lambda \sin\Delta \cdot \frac{\sin\left(l + \frac{n-1}{2}a\right)\sin\frac{na}{2}}{\sin\frac{a}{2}};$$

where

$$\sin l = \frac{\sin D}{\sin\Delta},$$

and

$$n = \text{number of days during which the sun does not set,}$$

and

$$a = 59' \, 8''.$$

But it is evident that

$$l + \frac{n-1}{2} \delta = 90^\circ \quad q.p.;$$

and, therefore, (15) reduces to the following expression:—

$$\left.\begin{array}{r}\text{Total heat received during the}\\ \text{time that the sun never sets}\end{array}\right\} = 2A \cdot \pi \sin \lambda \sin \Delta \cdot \left(\frac{\sin \frac{n a}{2}}{\sin \frac{a}{2}} \right). \qquad (16)$$

At the Pole itself, since the sun never sets, this expression, summed for half a year, gives the total heat received.

If we calculate from the Equator to the Arctic and Antarctic Circles, by equation (13), and from thence to the Poles, by equations (12) (with D for Δ) and (14), we obtain the following Table:—

Table showing the Total Heat received from the Sun at various Latitudes in the course of a Year.

Latitude.	Feet of Ice melted.	$\frac{A \cos \lambda}{\text{Feet of Ice}}$	Difference.
0°	97·8	97·8	0·0
10	96·5	96·3	0·2
20	92·4	91·9	0·5
* 23 18′	86·7	—	—
30	85·9	84·7	1·2
40	77·3	74·9	2·4
50	66·8	62·9	3·9
† 52 30′	61·4	—	—
60	55·7	48·9	6·8
‡ 66 32′	46·6	—	—
70	46·3	33·4	12·9
80	41·9	17·0	24·9
90	40·5	0·0	40·5

The average thickness of ice melted over the entire surface of the globe (allowing for the greater areas of the lower latitudes), by the annual sun heat, as deduced from the foregoing figures, is exactly 80 feet.

* Tropics of Cancer and Capricorn.
† Mean Latitude of Ireland.
‡ Arctic and Antarctic Circles.

The foregoing Table is constructed on the supposition that equal quantities of sun heat are absorbed by the atmosphere at all zenith distances; but, although this supposition is only a first approximation, yet by comparing the total quantities of sun heat at each latitude with the Table of Mean Annual Temperatures, given in pp. 108–9, some valuable conclusions may be drawn relative to the absolute radiation of heat into space from the earth's surface regarded as a whole. Let—

T = annual sun heat at a given latitude measured in feet of ice, in last Table (p. 160);

θ = mean annual temperature of a given latitude;

k = an unknown coefficient;

R = unknown radiation into space at that latitude.

Assuming that θ, the mean annual temperature of a given parallel of latitude, is proportional to the heat *retained*, we have—

T = total heat *received;*

$k\theta$ = heat *retained;*

R = heat *lost* by radiation;

and, therefore,

$$T = k\theta + R.$$

This gives us, in the Southern Hemisphere, the following seven equations:—

0°	. . . $97{\cdot}8$	$= 80{\cdot}1\,k + R.$	(1)
10	. . . $96{\cdot}5$	$= 78{\cdot}7\,k + R.$	(2)
20	. . . $92{\cdot}4$	$= 74{\cdot}7\,k + R.$	(3)
30	. . . $85{\cdot}9$	$= 66{\cdot}7\,k + R.$	(4)
40	. . . $77{\cdot}3$	$= 57{\cdot}9\,k + R.$	(5)
50	. . . $66{\cdot}8$	$= 47{\cdot}8\,k + R.$	(6)
60	. . . $55{\cdot}7$	$= 35{\cdot}3\,k + R.$	(7)

Any two of these equations will determine k and R; and hence we have 21 combinations for finding their values.

These all give consistent results, and the mean values of k and R, derived from the 21 combinations, are—

$$k = 0·8995.$$
$$R = 22·405 \text{ feet of ice.}$$

As the distribution of heat near the equator is disturbed by the motions of the heated water, so that the parallel of 10° N. is actually hotter than the equator (*vide* pp. 108–9), I have made another calculation, throwing out 0° and 10°, which reduces the combinations (from 20° to 60°) to 10 in number. The result of this calculation is—

$$K = 0·8512.$$
$$R = 22·60 \text{ feet of ice.}$$

The agreement of these results with the former shows that our formula represents well the whole of the Southern Hemisphere, whose annual radiation of heat may be represented by 22 feet of ice melted.

In the Northern Hemisphere we have the following nine equations—

0° . . .	$97·8 = 80·1\,k + R.$	(1)
10 . . .	$96·5 = 81·0\,k + R.$	(2)
20 . . .	$92·4 = 77·6\,k + R.$	(3)
30 . . .	$85·9 = 67·6\,k + R.$	(4)
40 . . .	$77·3 = 56·5\,k + R.$	(5)
50 . . .	$66·8 = 43·4\,k + R.$	(6)
60 . . .	$55·7 = 29·3\,k + R.$	(7)
70 . . .	$46·3 = 14·4\,k + R.$	(8)
80 . . .	$41·9 = 4·5\,k + R.$	(9)

These nine equations furnish 36 combinations for finding k and R, and of these 33 give consistent results; but three combinations, viz.:—

$$(0° - 10°), \quad (0° - 20°), \quad \text{and} \quad (10° - 20°),$$

give results inconsistent with the others, in consequence of the cause already stated. The mean values of k and R deduced from the remaining 33 combinations are—

$$k = 0{\cdot}7285.$$

$$R = 34{\cdot}385 \text{ feet of ice.}$$

If we throw out altogether the latitudes 0° and 10°, and calculate from the remaining 21 combinations (from 20° to 80°), we find—

$$k = 0{\cdot}7141.$$

$$R = 35{\cdot}475 \text{ feet of ice.}$$

The agreement between the results calculated from all latitudes and those found by omitting the low latitudes is not quite so close in the Northern as in the Southern Hemisphere; but our formula is fairly justified, and we are entitled to conclude that the annual heat lost by radiation in the Northern Hemisphere may be 35 feet of ice melted.

It follows, that the mean annual radiation of heat from the whole earth would suffice to melt a coating of ice 28·5 feet in thickness; but as the sun heat received is equivalent to 80 feet of ice, we have 51·5 feet of ice representing heat not accounted for as heat, for the mean temperature of the earth's surface is not increased.

This balance of heat is expended in two ways:—

1. It is converted into the Geological work done by rainfall and rivers.

2. It is converted into Chemical and Vital work done by the vegetable and animal organisms that clothe the surface of the earth.

The geological work done by rainfall and rivers can be shown to absorb a very small portion of the surplus sun heat.

The mechanical work done in crushing to fine powder a cubic foot of rock can be estimated from the following *data*, taken from the stamps of Polberro Tin Mine. Each stamp weighs 600 lbs., and is lifted and falls through 9 inches 45 times in one minute. Each stamp crushes into fine powder 28 cwt. of tinstuff in 24 hours.

Hence,

$$\left.\begin{array}{r}\text{Work done in crushing}\\ \text{one cubic foot of rock}\end{array}\right\} = 713{\cdot}5 \text{ ft. tons.}$$

By a calculation similar to that on page 128, we find—

$$\left.\begin{array}{r}\text{Work done in melting}\\ \text{one cubic foot of ice}\end{array}\right\} = 2850{\cdot}5 \text{ ft. tons.}$$

The latter number is almost exactly four times the former, from which I conclude that

The work done in melting one cubic foot of ice would suffice to crush into powder four cubic feet of rock.

I have shown (p. 94), that the geological work done by rain and rivers takes 3090 years to crush and carry to the sea one cubic foot of surface rock; hence we see that one foot thick of ice (representing sun heat) would account for the present geological work of 12,360 years!

NOTE C.—ON THE EVAPORATION FROM A FREE WATER-SURFACE AT VARIOUS LATITUDES.

If we collect together the statements respecting evaporation given already in the text, we find :—

PLACE.	Number of Years.	Latitude.	Annual Evaporation.	Mode of Observation.
1. Madras, . .	13	14° N.	91·25 in.	Cylindrical copper vessel, afterwards compared with a Tank.
2. St. Helena,	3	17 S.	83·78 ,,	Glass cylinder 6 in. diameter in tub of water, the levels being same inside and outside.
3. Bombay, .	—	18 N.	42·00 ,,	Tank = two sq. miles.
4. Nagpúr, .	—	29 N.	73·15 ,,	Tanks.

Using the formula, p. 124—

$$e = a \cos \lambda$$

we find—

Annual Evaporation at Equator (a).

1. Madras Observations, . . = 93·9 inches.
2. St. Helena ,, . . = 87·5 ,,
3. Bombay ,, . . = 44·1 ,,
4. Nagpúr ,, . . = 83·3 ,,

Rejecting the Bombay observations, as being inconsistent with the others, we find as a mean result of tropical evaporation, that the mean amount of evaporation at the equator is

$$a = 88{\cdot}23 \text{ inches.}$$

This amount of evaporation would give an average of 85·6 inches all over the torrid zone, or mean rainfall of 64·2 inches in the tropics.

The Continental rainfall in the tropics was shown, pp. 121–2, to be 67·7 inches, and the insular rainfall 61·5 inches;* so that, probably, all the sea-water evaporated in the tropics falls back again as rain in the same region.

The following admirable observations, made on the Burgundy Canal, in France,† show that in temperate regions, also, the rainfall does not differ much from evaporation, so that, probably, all parts of the earth give back, as rain, nearly all the water evaporated.‡

LOCALITY.	Altitude.	Number of Years.	Rainfall.	Evaporation.	Difference.
	metres.		inches.	inches.	inches.
1. St. Jean de Losne sur la Saône,	180	20	30·8	25·9	4·9
2. Dijon, ...	240	20	27·7	26·2	1·5
3. Pouilly, ...	400	20	30·4	22·4	8·0
4. Montbard, . . .	215	20	27·2	23·2	4·0
5. Laroche sur Yonne,	87	10	22·4	21·7	0·7

* The mean annual tropical rainfall, derived from the 110 Continental Stations and the 17 Insular Stations, is 66·84 inches.

† *Atmidométrie; Recherches expérimentales sur l'Evaporation*, par A. Collin (Orleans, 1866).

‡ The Evaporation and Rain Gauges employed were uniform, and made of square masonry, 2·50 metres on each side, and 0·40 metre in depth.

In the year 1860, I made observations, on the roof of the Trinity College Magnetical Observatory, with a cylindrical glass vessel, 8 inches in diameter, and found that the year's evaporation exceeded the year's rainfall by 1·62 inches. I checked this result, in the following year, by the use of an earthenware glazed cylindrical vessel, 17½ inches in diameter, and found that the year's evaporation exceeded the year's rainfall by 0·543 of an inch.

The following observations, made during the summer months, at Tiflis,* for three years, although not reliable as *absolute* measurements, are of importance *relatively*, as showing the intimate relation between the amount of evaporation in a given time, and the temperature of the air.

Daily Evaporation, Temperature of Air, and Rainfall at Tiflis.

	Mean Daily Evaporation.	Temperature of Air.	Ratio.	Monthly Rainfall.
	mm.			mm.
April, ...	2·8	12°·6 C.	0·223	25·5
May, ...	4·1	19 ·1 ,,	0·215	61·8
June, ...	4·8	21 ·5 ,,	0·224	72·2
July, ...	6·4	23 ·8 ,,	0·269	56·9
August, ...	6·7	25 ·6 ,,	0·262	19·1
September, . . .	4·4	19· 9 ,,	0·221	75·7

* *Nöschel, Repertorium für Meteorologie* (vol. v.).

LECTURE IV.*

THE RIVERS AND LAKES OF EUROPASIA.

LADIES AND GENTLEMEN,

In the Second Lecture, I have given an account of the mountain chains which form the skeleton of Europasia. The general effect of this structure is to reduce the northern half of the great continent to a vast system of low plains or steppes, and to make the southern half, more or less, a highland country, abounding in lofty plains, or table-lands. Fig. 23 shows the general effect.

The highlands of Europe, with the exception of the Scandinavian peninsula, are all in the south: Spain, Switzerland, Greece; and passing into Asia, we find in the south the tablelands of Asia Minor, Syria, Arabia, Persia, and lastly, the great central tableland of Asia, culminating in the lofty plateau of Thibet.

The rivers and lakes of Asia naturally take their physical features from the formation of the continent shaped out by its intersecting mountain chains—and may be most readily understood by their relation to the great central tableland.

The Red Sea and Valley of Jordan.—The Red Sea and Valley of Jordan, in continuation, form a narrow cleft of great depth, inserted between the tablelands

* This Lecture was delivered on *Lady Day*, 25th March, 1876.

Sea level to half a mile. Half a mile to one mile. Above one mile.

Fig. 23.

of Arabia and Abyssinia; and when we consider the height of the neighbouring lands and the great depth of the sea (p. 46), we must regard the Red Sea as the record of some great geological "down-throw," similar to those which appear to have generally marked out the outlines of many of our continents.

The river Jordan* flows from north to south, through the waters of Merom (100 feet above the sea level), into the Sea of Galilee (328 feet below the sea level), and finally loses itself in the salt waters of the Dead Sea (1390 feet below the level of the Mediterranean).

There can be no doubt that, at some former period, the Jordan flowed into the Gulf of Akabah, at the north end of the Red Sea. At that time, the Dead Sea must have had a much higher level, and have been a fresh-water lake, as the Waters of Merom and the Sea of Galilee† now are.

In fact, all lakes that have an outlet are fresh-water; but when the outlet is cut off, if the river that flows through the lake is unable to form a new outlet, it is certain that the evaporation from the surface of the lake exceeds the supply of water brought by the river; and the level of the lake will continue to fall until the mean annual evaporation from its surface becomes exactly equal to the mean annual supply of water brought in by the river and rainfall.

This process has been carried so far in the case of the Dead Sea, that its level is now actually 1390 feet below the mean level of the sea.

The lake must become salt, while undergoing the

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* The name signifies "The Descender," ירדן, from ירד, *descendit*.

† All through the Gospels, the Sea of Galilee is famous for its fishermen and its draughts of fishes.

transformation just described, for the river continually brings down soluble salts, washed from the soils traversed by it, and as these soluble salts have no outlet, they continually increase and make the water more and more salt.*

The Jewish people, and the Syrian highlanders, inhabiting the hill countries of Palestine and Syria, were a perpetual nuisance to the more powerful countries that surrounded them—Egypt, Chaldæa, and Phœnicia. They possessed all the enthusiasm and warlike spirit that has always characterised highlanders and islanders in every age of the world, and made them more influential in history than the tamer and more servile races that have lived on the great plains of the world, generally in degrading bondage to irresponsible masters.

The deep cleft through which the "Descender," flows formed a line of defence which a few could hold against many, and often proved of service in cutting off the retreat of an enemy or invader.†

If Asia furnishes us, in the Dead Sea, with the lowest surface of water that exists on the earth, she also furnishes us with the highest water surfaces, in Lakes Sirikol (15,600 feet), Manasorowara (17,000 feet), and Goorgoo (19,000 feet), all of which are situated on the famous "Terraced Roof of the World."‡ We thus have, existing in the same continent, two sheets of water differing in their level by more than 20,000 feet!

* The specific gravity of Dead Sea water is 1240, while that of sea water is only 1024.

† *Vide* Judges iii., 28–9 (*Moabites*, 10,000 men).
Judges vii., 24–5 (*Midianites*).
Judges xii., 5–6 (*Civil War*, 42,000 men).

‡ *Vide* page 42.

The Mediterranean Sea.—The Mediterranean Sea itself affords a grand example of a sea whose evaporation exceeds its rainfall and river supplies:—for a constant current is known to set through the Straits of Gibraltar from the Atlantic, and the magnitude of this current must be the exact measure of the difference between evaporation and water supply. It follows from this fact, that the Mediterranean must be growing more and more salt, like the Dead Sea, because it has no outlet.

The Black Sea, on the other hand, supplies us with an example of a sea whose evaporation falls short of its water supply; for the water furnished by the Danube, Dnieper, and Don, added to the rainfall, so far exceeds the evaporation, that a smart current passes from east to west, continually, through the Bosporus and Hellespont.

If, in the course of geological changes, the Straits* of Gibraltar should become closed, the surface of the Mediterranean would become lowered, until the evaporation from its lessened surface should equal, and not exceed, its supply from rainfall and rivers; this, in all probability, would require such a reduction of level as would convert into dry land the shallow barrier† that now runs from Italy, through Sicily and Malta, to Tunis and Tripoli, separating the two deep basins of the Mediterranean from each other.‡

The existence, in recent geological times, in Sicily, of *Elephas antiquus*, of the African elephant, and of an extinct hippopotamus; and, what is still more wonderful,

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* Nowhere 1300 feet deep.

† Nowhere 2000 feet deep.

‡ The depth of the eastern basin ranges from 6000 to 13,000 feet; that of the western basin averages 9000 feet.

the discovery of several species of elephant and of a hippopotamus in caverns in the small island of Malta, render it necessary to suppose the existence of a land connexion between Italy and Africa. It is interesting to observe that this might be effected, as shown above, by geological changes of small amount at the Straits of Gibraltar, without the necessity of admitting an actual elevation of the sea bottom between Sicily and Carthage.

The Europasian Basin of the Continental Streams.— One of the most striking physical features of Europasia is the area called the Basin of the Continental Streams, which flow, not into the general ocean, as happens in most cases, but into inland salt lakes, some of which are, like the Dead Sea and Sea of Galilee, below the sea level.

In Fig. 24 I show the Europasian Continent and the basin of the Continental Streams, occupying more than one-third of the area of the whole continent. This is a phenomenon not paralleled in any other continent, and demonstrates that although, as shown in Fig. 23, Europasia consists largely of tablelands, yet, on the whole, the continent must be saucer-shaped, compelling the Continental Streams to flow towards a central shallow depression.

The Seas or Lakes, necessarily salt, into which the Continental Streams discharge are, chiefly: the Caspian Sea,* the Aral Sea, Lob Lake, and Balkash Lake.

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* The level of the Caspian Sea is 84 feet *below* that of the Mediterranean, and the level of the Aral Sea is 33 feet *above* the same.

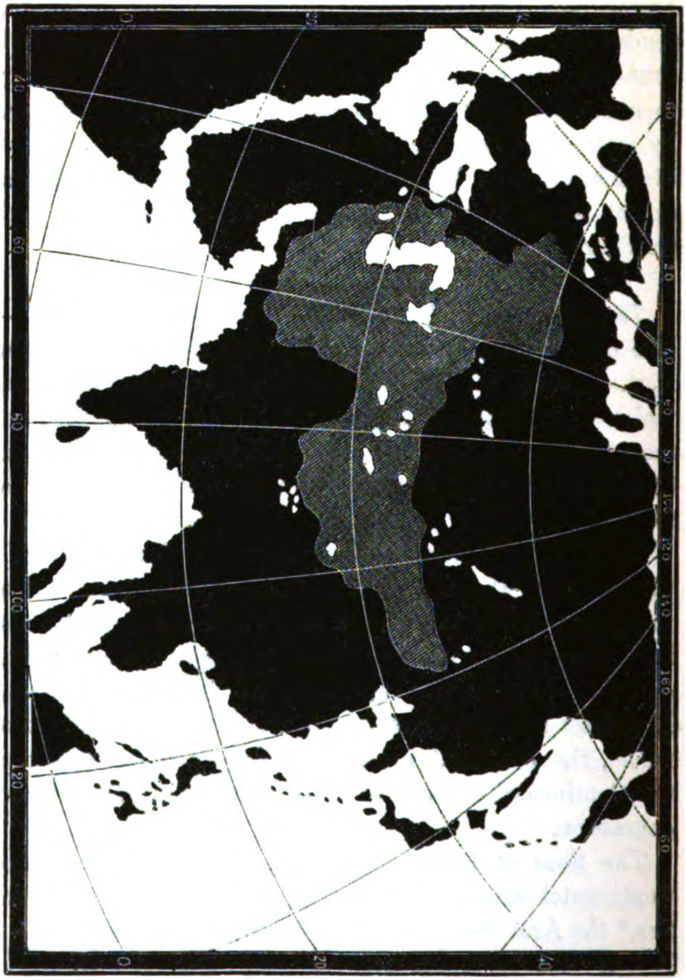

Fig. 24.

Of these, the Caspian is fed by the rivers Volga, Ural, and Kour; the Aral by the Sir Daria (*Jaxartes*) and Amu Daria (*Oxus*);* and the Lob Lake by the rivers of Yarkand and Kashgar. The river basins drained by these rivers are:—

1. The Volga, ...	397,460	sq. gr. miles.
2. The Ural, ...	83,200	,, ,,
3. The Kour, ...	64,640	,, ,,
4. The Sir Daria, . . .	237,920	,, ,,
5. The Amu Daria, . .	193,600	,, ,,
6. The Lob rivers, . .	177,120	,, ,,
Total, . . .	1,153,940	sq. gr. miles.

This represents a rain basin larger than that of the Nile, and two-thirds of that of the Amazons, the largest river in the world.

The climate of Central Asia is continental in the extreme: in summer the sands are sufficiently hot to roast eggs (100° F.), and the naked hand cannot be placed upon iron which has been exposed to the sun; while in winter the lakes and rivers are frozen over to a thickness of many feet.

The severity of the climate in this part of Asia may be estimated by a comparison of the January and July temperatures of Astrachan, on the northern shore of the Caspian Sea, and of Dublin, on the east coast of Ireland.

Mean Temperatures.

Locality.	January.	July.	Range.
Astrachan,†. . . .	19°·5 F.	77°·4 F.	57°·9 F.
Dublin, ...	38 ·5 ,,	60 ·8 ,,	22 ·3 ,,

* This famous river takes its origin from Lake Sirikol, whose surface is 15,600 ft. above the sea level.

† The mean temperatures of December, of January, and of February, are all below the freezing point of water.

The Rivers of Mesopotamia.—The famous plain of Mesopotamia is watered by the double river system of the Euphrates and Tigris. Both rivers take their origin in the Armenian Highlands, and unite their great streams at Kornah, about 90 miles from their delta, at the head of the Persian Gulf. The great plain of Mesopotamia is less than 500 feet above the sea level, and has an average breadth of 150 miles; the two rivers run in parallel streams through the greater part of the length of Mesopotamia, for a distance of 400 miles.

The Euphrates, which is the western stream, has a total length of 670 miles in this plain, and is nowhere 500 feet above the sea level. The famous Babylon (*Hillah*) was situated on this river, at a distance of 280 miles from its mouth.

The Tigris has a total length in the same plain of 530 miles, and the famous Nineveh (*Mosul*) stood on its banks, at 520 miles from the sea, close to the point at which the Tigris emerges from the lower highlands.

The Upper Euphrates is formed by the union of two streams, which have their gathering ground on the southern slopes of Mount Ararat, and the mountains that surround Erzeroum. The total length of the Euphrates is at least 1600 miles.

For 180 miles above the point where the Euphrates enters the plain of Mesopotamia, to the point where it leaves the mountains, it presents the appearance of a "river of the first order, struggling through high hills, in an exceedingly winding course, as it endeavours to force its way over a rocky bed, from one natural barrier to another, the velocity of its current varying from rather more than two miles per hour to four and a-half per hour, according to the season of the year and the nature of its bed."

Modern investigations have proved the Euphrates not to be navigable for river steamers; and, if ever the plain of Mesopotamia is again to take its place in history, it will be by the aid of locomotive engines, and not by that of steam-boats.

The description I have given of the Upper Euphrates applies, *mutatis mutandis*, to the Upper Tigris. Its gathering ground is from the slopes of the mountains surrounding Lake Van,* ranging over 5000 feet in height. Its course is shorter and less circuitous than that of the Upper Euphrates, but on entering the plain its volume of water is somewhat greater than that of the Euphrates. Like that river, its lower portion is not navigable for steam-boats, owing to sand and mud banks.

The united stream of the sister rivers is called the Shat el Arab,† and its bar is formed of fine mud, and very shallow—its deepest channel being only 18 feet in depth.

The extreme flatness of the lower part of Mesopotamia may be estimated from the fact that the tide flows up the Tigris to a distance from Kornah of 35 miles, and to a distance up the Euphrates of 60 miles.

The rain-basin of the valley of Mesopotamia is 195,680 geographical square miles. During the melting of the snows on the mountains of Armenia, the Euphrates and Tigris overflow their banks, and the lower part of the plain of Mesopotamia presents a striking resemblance to the rival plain of Egypt during the floods of the Nile. The floods of Mesopotamia, however, produce no such fertilising results as those of the Nile, and the whole

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* Lake Van, like the Dead Sea, has no outlet, and contains large quantities of carbonate of soda and chloride of sodium.

† The river of the Arabs.

country presents the appearance of a barren wilderness, where, formerly, were great cities, and countless millions lived in the midst of plentiful harvests—

"It (Babylon) shall not be inhabited for ever;
And it shall not be dwelt in from generation to generation;
Neither shall the (1)Arab pitch tent there,
Neither shall shepherds cause [their flocks] to lie there.
But there shall lie (2)desert creatures;
And their houses [viz., of the Babylonians] shall be filled with (3)howling animals;
And there shall dwell the (4)daughters of the ostrich;
And (5)shaggy beasts shall gambol there.
And (6)jackals shall howl in his [the king of Babylon's] widowed mansions,
And (7)wolves in the temples of pleasure."

Isaiah xiii., 20–22.

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(1) Travellers remark that the Bedouin Arabs still have a superstitious dread of lodging on the site of Babylon. The Rev. Joseph Wolff, speaking of his visit to Babylon, says: "I inquired of them (the Yezeedee), whether the Arabs ever pitched their tents among the ruins of Babylon. 'No,' said they, 'the Arabs believe that the ghost of Nimrod walks amidst them in the darkness, and no Arab would venture on so hazardous an experiment.'"

(2) צִיִּים. This word denotes properly those animals that dwell in *dry* and desolate places (from צִי, a dry region), literally "droughty ones." The LXX. render the word simply *θηρία*, wild animals. The word is applied to *men* in Ps. lxx., 9; lxxiv., 14, and to animals in Isaiah xxiii., 13; lxxiv., 14; Jer. l., 39. Bochart supposes that by the word in this place, *wild cats* or *catamounts* are intended. He has proved that they abound in Eastern countries.

(3) אֹחִים properly *howlings*, hence, howling animals, "groaners," "howlets." Gesenius says that the word probably denotes "screech-owls."

(4) בְּנוֹת יַעֲנָה "The daughters of the ostrich" is an oriental idiom for ostriches in general. יָעֵן, an ostrich, so called (according to Gesenius) from its greediness and gluttony. (יְעֵן, Syr., to be greedy, voracious.) Bochart has gone into an extended argument to prove that the ostrich is intended here. (*Hier.* ii., ch. xiv.)

(5) שְׂעִירִים "hairy (or shaggy) ones." Vulgate, *pilosi*. Commonly applied to the goat (Lev. iv., 24), but here referred by some, with much probability, to the baboon. "The Moko, or Macacus Arabicus, is at present

The Rivers of the Himalaya.—Three magnificent rivers are fed by the rain that falls on the giant slopes of the Himalaya—and the rainfall of parts of these mountains exceeds that of any other part of the world. These rivers are—

Rain-basins.

1. The Indus,	. . . .	312,000 sq. miles.
2. The Ganges,	. . . .	319,010 „ „
3. The Brahmapûtra,*	. .	292,140 „ „
Total,	. . .	923,150 sq. miles.

The Indus waters the western, and the Ganges the eastern part of the fertile plain of Hindostan, while the

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found in Babylonia."—(Dr. Tristram, "B. N. H."). One of Jerome's explanations is "*Silvestres quosdam homines*, quos nonnulli fatuos ficarios vocant."

(6) אִיִּים. The word אִי properly denotes *howling, cry*. Hence, as a concrete, "a *howler*," *i.e.* a jackal. The word only occurs in this place, and in Is. xxxiv. 14.

(7) תַּנִּים. The word תַּן, (only in plur. תַּנִּים), a certain beast dwelling in deserts, Is. xiii. 22; xxxiv. 13; xliii. 20 (whence the desert is called מְקוֹם תַּנִּים, Ps. xliv. 20). Bochart (*Hier.* ii., p. 429) takes it to be *great serpents*, as if it were the same as תַּנִּין; but among the Hebrews, R. Tanchum of Jerusalem correctly explains this word "*jackal*, wild dog," so called from its cry. Compare Arab. تنان, *wolf*, both from the root תָּנַן. The use of the word jackal to denote תַּנִּים is supported by the fact that this word is found in Lam. iv. 3: "They draw out the breast, and give suck to their young."

The latest writers seem to be agreed that איים and תנים are different appellations of the jackal; but, in order to retain the original variety of expression, they substitute another animal in one of the clauses, such as *wolves* (Gesenius), *wild cats* (Ewald). "The site of Babylon," says Mr. Layard, "is a naked and hideous waste." "Owls," he says, "start from the scanty thickets, and the foul jackal stalks through the furrows." (*Nin. and Bab.*, p. 484.)

* Including the Sanpoo Valley.

Brahmapûtra, having drained the northern slopes of the Himalaya, flows through Assam, and unites its delta with that of the Ganges at the head of the Bay of Bengal.

On the northern slope of the western Himalaya (Lat. 31° N., Long. 81° E.), in the lonely solitude of the snow-clad mountains, at an elevation of 17,000 feet above the sea level, are situated the famous sacred lakes *Manasarowara* and *Rawan Rhad* (each about 15 miles long by 11 broad), surrounded by tremendous rocks, above which rise the loftiest summits of the Himalaya.

To have once seen the surface of the sacred *Manasarowara* is, to the devout Hindoo, a felicity beyond every other on earth. The lakes are close together, but the rain which falls on each follows a widely different course—for, the *Manasarowara* is the source of the Brahmapûtra,* and the *Rawan Rhad* is the source of the Suttlej.

The Thibetan tradition (borrowed from the Hindoos) is, that four of the great Hindostan rivers flow from the mouths of as many animals—

> The Brahmapûtra (Sanpoo), from the horse's mouth;
> The Ganges, from the peacock's mouth;
> The Suttlej, from the elephant's mouth;
> The Indus, from the lion's mouth.

The Indus takes its origin close to the sacred lakes, and flows to the north-west, between the Himalaya and the Kuenlun mountains, for a distance of nearly 600 miles; here it turns abruptly to the south-west, piercing in its passage the Hindoo Koosh mountains.

The Indus continues its south-west course, from the point where it changes its direction, for a distance of

* The upper Brahmapûtra is the Sanpoo river.

1000 miles, entering the Indian Ocean (Gulf of Oman), near Kurrachee.

At Attok, the Indus receives from the west the Cabul river; and the united stream, although only 286 yards in width, is of very great depth, and flows at the rate of six miles per hour: even when the river is lowest, the stream is full of waves and eddies, and produces a sound like that of the sea; but when it is swelled by the melting of the snow in summer, it forms a tremendous whirlpool, the roaring of which can be heard at a great distance, and which often swallows up boats or dashes them against the rocks.

Nearly 400 miles below Attok, the Indus receives from the east the famous Punjnud,* formed by the union of the five well-known rivers, which give the name of Punjaub* to the whole country.

These rivers are, from north to south:—

1. The Jailum (*Hydaspes*), which drains the valleys of Cashmere and Garets.
2. The Chenaub (*Acesines*).
3. The Rawee or Lahore river (*Hydraotes*).
4. The Chara or Beyah (*Hyphasis*).
5. The Suttlej (*Hesudrus* or *Zaradrus*).

The first four of these tributaries have their gathering ground on the southern slopes of the Himalaya; but the Suttlej, like the Indus itself, collects its upper waters from the rainfall of the northern slopes. As already mentioned, it takes its chief origin from the sacred lake Rawan Rhad, and its highest source is said to be

* "The five rivers."—Panj-âb and Panj-nad signify the same thing; the terminations âb and nad being, respectively, Persian and Sanskrit.

at a place called Chomik-Tongdol, where a small stream issues from the ground and flows into a little lake called Goorgoo, 19,000 feet above the sea level.

The tributaries of the Punjnud, like the Indus itself, are characterised by a rapid flow, and the lower part of the river forms a delta presenting a face, 125 miles long, to the sea; and in this delta, owing to the rapid motion of the water, the channels of navigation are constantly shifting, and therefore dangerous. The consequence is, that there is no known river, discharging even half the water of the Indus, that is not superior for commercial purposes to this ancient and far-famed river. The area of the rain-basin of the Indus is 312,000 geographical square miles, and its length is 2260 miles.

The *Ganges* and its northern tributaries drain the southern slopes of the Himalaya, from Kunchinjunga (28,178 feet), (*Darjiling*), on the east, and Dhawalagiri (27,500 feet), in the centre, to *Kotgur* on the west, along a crest of snowy mountains not less than 800 miles in length, and having a mean altitude of nearly 20,000 feet.

The source of the sacred Ganges is the Bhâgîrathî,* a mountain torrent issuing from a glacier, near Gangoutri, at a height of 13,800 feet above the sea level. This sacred place is separated by less than ten miles of snowy crest from one of the tributaries of the upper Suttlej, flowing down the northern slope of the Himalaya.

Thus, if a circle of ten miles in diameter be described touching the southern and adjacent shores of the sacred

* This word is a patronymic from Bhagîratha, an old king who is said to have brought down the Ganges from Heaven.—*Schlegel*, Râmâyana lib. i. cap. 36, *seqq*.

lakes, Manasarowara and Rawan Rhad, the winter snows that gather inside this circle, when touched with the breath of the summer wind, will discharge three several streams—to the west, through Rawan Rhad into the Suttlej and Indus; to the east, through the Manasarowara, into the mysterious Sanpoo and Brahmapûtra; and to the south, into the Gogra that flows past Oudh, and joins the sacred Ganges, about 40 miles above Patna.

The Bhâgîrathî, or true Ganges, is worshipped as a goddess, under the name of Gunga, daughter of Brahma; and its waters, at the junction of five of its tributaries, have the power of washing away the sins of believers; these junctions are called *prayagas*, and four of them occur in the mountains, before the Ganges enters the plain of Hindustan, which it does at Hurdwar.* At Hurdwar, the Ganges is only 1800 feet above the sea level, having fallen 12,000 feet during its short run in the mountains of 200 miles; this represents a fall of 60 feet per mile, which is that of a mountain torrent. From Hurdwar to the delta of the Ganges in the Sunderbunds, the total length of the main stream is 1730 miles, which represents a mean fall of 12·05 inches per mile. The consequence is, that the Ganges (unlike the Indus) is navigable for upwards of 1700 miles.

The Ganges receives a vast multitude of tributaries, twelve of which are larger than the Rhine.

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* Multitudes of pilgrims assemble annually at Hurdwar, either to bathe in the Bhâgîrathî, or have its waters poured over them, at one or other of the sacred *prayagas*, or junctions. It has frequently happened that the pilgrimage of the Hindoos to Hurdwar, like that of the Mahommedans to Mecca, has been the fountain-head from which *cholera* has invaded Europe from the East.

Its most important tributary is the Jumna, which joins the Ganges at Allahabad, 700 miles below Hurdwar. The Jumna is formed of northern tributaries draining the southern slopes of the Himalaya, the chief of which forms the well-known Dooab Canal; and of southern tributaries draining central India as far south as the Vindhya mountains in Bhopal, including the table-land of Malwa.

The general course of the Ganges from Hurdwar to the sea is south-easterly and easterly; at Hurdwar it enters the plain of Hindustan, a clear, beautiful, and shallow stream; from Hurdwar to Allahabad it is from one mile to one mile and a quarter in width; below Allahabad its course becomes more winding, and it attains a width of three miles; and at 500 miles from the sea its depth is 30 feet when the river is at the lowest. The floods of the Ganges commence in April, attain their maximum in the middle of August, and continue till October.

The maximum discharge of water* during the floods is 494,208 cubic feet per second; and the minimum discharge at low water is 36,330 cubic feet per second.

The *Brahmapûtra* takes its origin (p. 180) from the sacred lake of Manasarowara, from which it flows eastward, under the name of the Sanpoo, to Llassa, through Tibet, draining the northern slopes of the Himalaya for a distance of upwards of 1000 miles.

To the east of Llassa it turns suddenly to the south, bending round the eastern termination of the Himalaya range, and enters the plain of upper Assam, through which it flows, south-west, for 500 miles, when, turning southward round the western end of the Khasi and

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* At Ghazipoor.

Garrow Hills, it finally unites in forming a common delta with the Ganges, at the head of the Bay of Bengal. During its course through Assam, the Brahmapûtra drains the whole southern slopes of the Himalayas that lie to the east of Kunchinjunga, through a length of 600 miles, and receives in its lower course the tremendous rainfall of the Khasi Hills, amounting in some localities, as at Cherrapunji, to 559 inches* of annual rainfall—all of which comes down in the six wet months of the year. During the floods, from the middle of June to the middle of September, the plains of Upper Assam are an entire sheet of water, eight or ten feet deep.

The average rainfall of the plain of Assam is 84·5 inches per annum. The average rainfall of the Khasi Hills is about 277 inches, and that of the Himalaya, as at Darjiling and Rungbee, 150 inches.

The Brahmapûtra, although its rain-basin is somewhat less than that of the Ganges, is a much larger river, for its *minimum* discharge of water is 150,000 cubic feet per second,† while the minimum discharge of the Ganges, calculated for a similar position, would be 76,000 cubic feet per second.

The Brahmapûtra traverses Bengal for a distance of 400 miles, and attains a width of four or five miles, so that, but for the freshness of its waters, it would be mistaken for an arm of the sea.

The Brahmapûtra and Ganges form a united delta, or rather a union of two gigantic deltas, which are shown in Fig. 25.

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* This is the mean rainfall at Cherrapunji; in one year 800 inches of rainfall were recorded at a station near Cherrapunji.

† At Gwalpara, not many miles above the head of its delta (*Wilcox*).

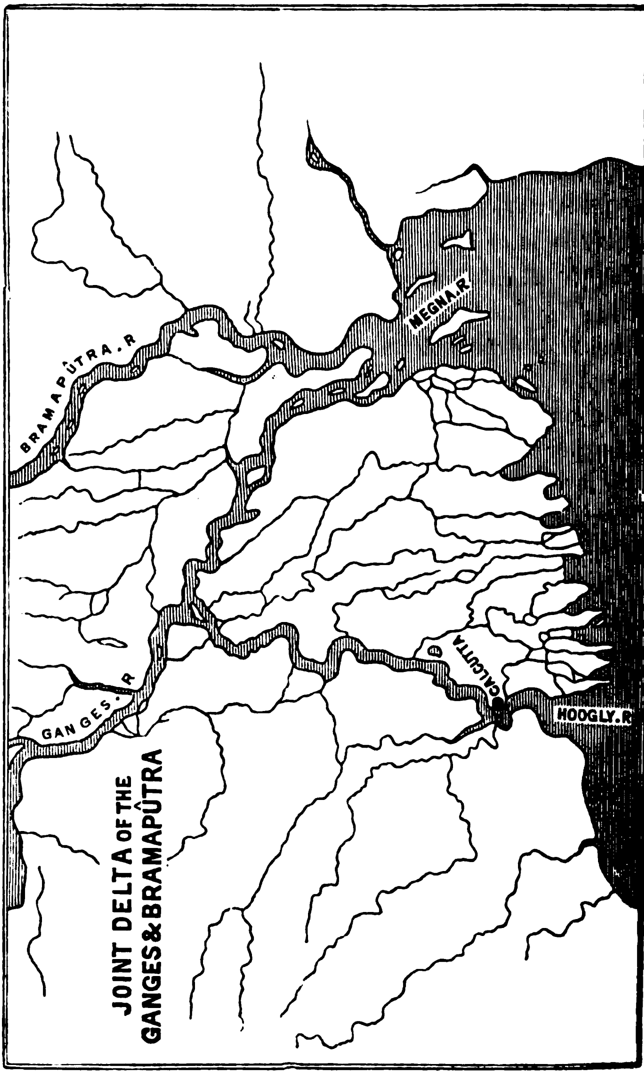
JOINT DELTA OF THE
GANGES & BRAMAPÛTRA
BRAMAPÛTRA.R
MEGNA.R
GANGES.R
CALCUTTA
HOOGLY.R

Fig. 25.

The sea front of the united deltas measures 200 miles, from the mouth of the Hoogly river (Ganges) on the west, to that of the Megna river (Brahmapûtra or Jummul) on the east. The delta proper (or land formed of river mud) extends in the form shown in Fig. 25, to a distance of 200 miles up both rivers, or 300 miles if measured on the windings of the rivers themselves.

The rain-basin of the united rivers is 611,150* square geographical miles in area. The importance of a river system is to be measured, not only by its rain-basin, but also by the annual rainfall on the area of the rain-basin, which, as I have already stated, is very great in the case of the rivers of Hindostan, supplied from the Himalaya.

The unusually great rainfall of the rain-basins of the Indian rivers depends partly on the great height of the Himalaya range, and partly on the *Monsoons*, which must be now described:—

The Monsoons† are periodical changes of wind, produced by a reversal of the north-east trade winds during the summer months of the northern hemisphere. If the whole surface of the earth were uniform, the north-east Trades would blow all the year round, from the Tropic of Cancer to the equator, in the northern tropical zone. But, when larger masses of extra tropical high land exist, during the summer months, owing to the increased declination of the sun, they become overheated, in relation to the mean temperature of their latitudes, and so produce currents of air, moving from the sea surface towards the heated surface of the land; and these currents of air are

* Including the Sanpoo Valley.

† So called, from the Arabic and Malay word "moussin," a season.

sufficiently powerful to *reverse* the Trade Winds during the summer months, and even to draw a portion of the regular south-east Trades out of their course, and convert them into south-west monsoons.

The south-west monsoons blow in India from April to October, and are reversed Trades.

The so-called north-east monsoons blow from October to April, and are simply the usual Trades of the northern hemisphere.

The south-west monsoons of India are caused by the desert of Gobi and the sun-burned plains of central Asia, the overheating of which, although they are above 30° N. latitude, affects the movements of the air in summer, even south of the Equator.

Other south-west monsoons are known in the Gulf of Guinea, on the west coast of Africa, and are caused by the sandy deserts of northern Africa.

In the New World there are Central American monsoons in the Pacific, caused by the heated plains of Utah and Texas; and monsoons in the Gulf of Mexico, caused by the dry lands of New Mexico.

The following account of the monsoons, as observed in Ceylon, has been supplied to me by one of my sons, who is in the Civil Service of that country :—

"There are two monsoons in Ceylon—the south-west and north-east. The south-west monsoon is the wet monsoon, and its period may be said to be from April till October. The north-east monsoon is the dry monsoon, and blows more or less from October till April. The monsoons are observed to the best advantage in the low country on the sea coast. In the interior, on the hills, the monsoons, from eddying in currents round and through the mountain zone in the centre of the island, lose their individuality to a great extent, and in the hills there is no real 'bursting' of the monsoon such as there is on the low flat coast, so that in the hills, though you know what monsoon ought to be blowing at a given time, it is sometimes difficult to recognise it, owing to the influence of the high mountains and deep valleys. On the coast, however, the monsoon is observed in all its grandeur, especially when it is overdue, and there has been a drought over the land. About April and May the weathercock gets bothered, and takes to racing round, and thinking of the west and south: this lasts for two or three weeks, until finally it points steadily to south-west, and then on comes the monsoon. The wind comes fresh from the south-west across the sea, and after a few days the crashing 'league-long' rollers on the beach show that the monsoon is advancing quickly. The barometer then falls suddenly, and the sky becomes dark and lowering, and there is a deathlike stillness over the country. Then the lightning flashes and the thunder roars, and the winds blow wildly from the south-west over the sea, and lash up the waves, the rain coming down in torrents over everything, and numerous 'water-spouts' being formed at sea. Sandbanks—the work of the north-east monsoon during its six months' prevalence—are torn to pieces, and washed over by the sea on the west coast in a few nights. Rivers rise thirty feet in a single night, the soil of their channels absorbing but little of the rainfall from the high mountains, and down pour the floods on the low country, to find the mouths of the rivers on the east coast more or less blocked up by the sea with sand. The result is widespread floods, which, if unusually heavy, are accompanied by considerable loss of life; but the rivers on the west coast being more numerous than on the east, and running through more populous districts, much greater damage is done from floods during the north-east monsoon on the west coast, than during the south-west monsoon on the east coast. Men and cattle are drowned, and whole rice crops ruined. The blocked-up mouths of the rivers have to be cut through to let off the floods. The 'bursting' of the monsoon lasts, in greater or less force, for three weeks or a month, during which time heavy rain pours incessantly. Then the weather clears, and the wind blows fresh and steady from the south-west for the next six months. Rain may be expected more or less all through this monsoon, which is called the wet monsoon, in contradistinction to the north-east monsoon, which is called the dry monsoon. About October or November similar phenomena occur on the east coast, only not on so grand a scale as in the case of the south-west monsoon, and then the wind blows from the north and east. Bars now commence to form at some of the mouths of the rivers on the east coast, and the mouths of the rivers on the west coast open until shut up again by the south-west monsoon.* When the north-east monsoon has burst, there is no more rain except on the east coast, and it blows over the whole island steadily, a cold noxious wind. On the west coast of Ceylon the north-east monsoon, for the first half of its reign, exerts a most baneful influence. It is called in Colombo on the coast the 'land wind,' or 'long-shore wind;' and, to escape it, those who can manage it leave Colombo for the hills. (This is the

* The fresh sea comes into the river, and the oysters at the mouths of some of the tidal rivers are then very good eating. The habits of the crocodiles in the large lagoons on the coast are regulated by these changes, as also are those of deer and other game in the forests.

'season' for Nuwara Eliya, the hill sanitarium.) The 'land wind' is a dry, chilling wind, and you instinctively feel that it is dangerous, and shut up all the doors and windows on the side of the house on which it blows. At night it is still more dangerous, and sitting even for a short time after dark in a verandah in this wind is to be avoided. Amongst its lesser evils are rheumatism and neuralgic cramps: it warps furniture and doors; and horses, once affected by it, never get over it. It brings with it colds of all sorts, fevers, agues, and dysentery. Cholera, too, comes with the north-east monsoon—during which its occurrence is more frequent than during the south-west. The dysentery brought by this monsoon is sometimes the terrible 'two-days' dysentery.'"

The south-west monsoon, or reversed Trade Wind of India, extends to the south-eastern boundary of the basin of the continental streams, shown in Fig. 24. This part of Asia is almost unknown, but it consists of lofty table-lands, running eastward into the southern districts of China; and the rainfall of the south-west monsoon, condensed on the slopes of the table-lands, constitutes the chief supply of three most important rivers, viz., the *Irawady*, the *Yang-tze-kiang*, and the *Hoang-ho*.

During years in which the summer heat of south-eastern Asia is less than usual, the south-west monsoon will fail to attain its usual north-easterly limits, and the consequence often is, the occurrence of serious famine in southern China, which depends largely for its crops on the waters of the *Yang-tze-kiang*.

Rivers of the South-eastern Peninsula.—The river system of this peninsula is composed of the Irawady, the Menam, and the Camboja, fertilising, respectively, the empire of

Burmah, the kingdom of Siam, Cochin China, and Annam, and their chief supply of rainfall is drawn from the mountain ranges running eastward of the Himalaya range.

Like the Ganges and Brahmapûtra, these rivers descend rapidly from their mountain chains, and then flow slowly, with slight inclination of their beds, through rich plains, which are fertilized by their periodic inundations. The importance of the Irawady will be seen from the calculations given in Note (B) at the end of this Lecture.

The Rivers of China.—The rivers of China unwater the whole eastern slope of the table-land of Central Asia, and the more southern rivers partake of the benefits of the south-west monsoon.

Three of these rivers are of first-class importance, as will be seen from the size of their rain-basins. Reckoned from south to north, they are as follows:—

	Rain-basin.
Hong-kiang (Canton river), .	99,000 g. sq. miles.
Yang-tze-kiang, ...	548,000 " "
Hoang-ho (Yellow river), .	538,000 " "
Amur, ...	583,000 " "

The Yang-tze-kiang and Hoang-ho almost form a twin system, like that of the Ganges and Brahmapûtra: the mouths of the two rivers are 90 miles apart, but the intervening space is occupied by a delta, which is the joint product of both rivers.

Like the Ganges and Brahmapûtra, the Hoang-ho and

Yang-tze-kiang take their first origin from mountain springs only a few miles apart, then separate during their long courses, the Hoang-ho flowing to the north, and afterwards to the south, for 2300 geog. miles; and the Yang-tze-kiang, flowing to the south and afterwards to the north, for 2900 geog. miles; both rivers flowing into a common delta. Thus they are united at birth, separated during life, and again flow together at death into the parent ocean. A distance of 1200 miles separates the two great rivers in their middle course.

The northern river, Hoang-ho, or "Yellow River," being so called from the great quantities of mud carried to the sea by its rapid stream, resembles the Indus in uselessness; for its bed being raised above the surrounding flat country, it constantly shifts its channel, and is valueless for commercial purposes.

During 2500 years of observation, recorded in the authentic Chinese annals, the Hoang-ho has nine times shifted its mouth of entrance into the sea, from 39° N. lat. (near Pekin) to 34° N. lat., its present embouchure, a distance of 350 miles. Disastrous inundations accompany each change of river bed, which have induced the natives to call their yellow river, the "Sorrow of Han."

The southern river, Yang-tze-kiang, on the contrary, is navigated by steam-boats for 1200 miles from its sea mouth, and discharges for China all the functions which the Ganges does for Hindustan.

The lower part of the course of the Yang-tze-kiang is so flat that the tide ascends the river for 450 miles: and this river and the Hoang-ho are connected together by innumerable canals, many of which are of a remote antiquity.

Their conjoint delta plain varies from 500 miles to

150 miles in width, and the sea front of the delta is estimated to gain upon the sea at the rate of 100 feet per annum.

The *Amur* river, called by the Mantchoos the "Saghalin," or Black water, is fully equal in importance to the other rivers of China, having a rain-basin of 583,000 g. sq. m., and a length of 2380 miles. It unwaters the north-eastern slope of the central table-land of Asia, and enters the Sea of Okhotsk, opposite the Island of Saghalin, in 53° N. lat. It is a deep and slow-moving river, and navigable through a great portion of its length; it has neither rocks nor shallows, and its banks are clad with magnificent forests. It forms, for 500 miles of its length, the boundary between Siberia and China; and in the future will constitute the chief outlet for the rich products of Southern Siberia, notwithstanding that its mouth is closed by ice during more than half the year.

The basin of the Amur was the scene of the wonderful exploits of Kenghis Khan.

The Rivers of Siberia.—The whole northern slope of the table-land of Asia is drained by the great Siberian rivers:—

Rain-basins.

1. The Lena, ...	594,400	geogr.	sq. miles.
2. The Yenesei, ...	784,500	„	„
3. The Irtish-Obi, . . .	924,800	„	„

These rivers would rank among the most important in the world, were it not that they all discharge into the Arctic Ocean, where their mouths are frozen during ten months of the year. The extraordinary flatness of the plain of Siberia helps also to enhance the importance of these rivers, as channels of communication.

Thus, Tobolsk, 550 miles from the sea in a straight line, is only 128 feet above its level, giving a slope of only 2·8 inches per mile (not including windings of the river).

Again, the basin of the Upper *Irtish*, which is 1750 miles from the sea in a straight line, and 1000 miles more measured on the river itself, is only 1900 feet above the sea-level. This gives a slope on the river itself of 8·3 inches per mile on the average.

Irkutsk is 1400 miles from the sea, in a straight line, and is 1246 feet above its level; this gives a slope (not counting windings) of 10·7 inches per mile.

Yakutsk, on the Lena, "the coldest of inhabited places," is 560 miles from the sea, and is 287 feet above its level; this gives a mean slope (not counting windings) of 6·15 inches per mile.

The *Yenesei*, in its course, derives a large proportion of its waters from the celebrated Lake Baikal, in south-eastern Siberia. This great lake is fresh-water, deriving its chief supply from the Salenga river; it is 1535 feet above the sea-level, and 1640 miles distant from the Arctic Ocean in a straight line (11·23 inches per mile).

This great lake is 360 miles long, and varies from 20 to 52 miles in width. The water freezes in November and thaws in May, and the ice attains a thickness of several feet.

The most astonishing physical feature of Lake Baikal is the extraordinary depth of its basin in some parts. In the upper lake, soundings of 12,356 feet have been made, exceeding the heights of Etna and Teneriffe. It will be seen from this that part of the bottom of Lake Baikal is nearly 11,000 feet below the surface of the sea.*

Compared with Lake Baikal, the Dead Sea (p. 170) is a mere crack in the earth's skin, for its greatest depth is only 1860 feet, which, added to its surface depression below the Mediterranean (1390 feet), gives a depth of only 3250 feet.

The famous fresh-water lakes of N. America are also mere shallow pits, scooped out of the earth's surface, as compared with this Siberian fresh-water lake.

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* This enormous depth almost equals that of the deepest part of the Eastern Mediterranean (13,000 feet), and brings the floor of Lake Baikal to the level of the mean floor of the ocean.

NOTE A.

Lengths and Rain-basin Areas of the Chief Rivers of Europasia.

Name of River.	Length in Geographical Miles.	Rain-basin in Geographical Miles.
Amur, ...	2380	583,000
Brahmapûtra, ...	—	292,140*
Danube, ...	1496	234,000
Euphrates,†	1492	196,000
Ganges , ...	1680	319,010
Hoang-ho, ...	2280	537,000
Indus, ...	1960	312,000
Irawadi,‡	2200	130,900
Lena, ...	2400	594,000
Mekong,§	2100	216,000
Obi, ...	2320	925,000
Rhine, ...	600	65,000
Tigris, ...	956	——
Volga, ...	2400	397,000
Yang-tze-kiang, ...	2880	548,000
Yenesei, ...	2800	785,000

* Original calculation from Stanford's Orographical Map of Asia.

† Including the rain-basin of the *Tigris*.

‡ Including the rain-basin of the *Martaban* (or *Saluen*).

§ Including the rain-basin of the *Menam*.

Note B.

On the Annual Water-discharge of the Ganges, Brahmapûtra, and Irawady.

The Rev. Mr. Everest, in 1831–32, instituted a series of observations and experiments on the Ganges, at Ghazipûr, a little below Benares, and 500 miles from the mouth of the river, at the Hoogly.

From these experiments, the following facts were obtained:—

Water-discharge.

	Cubic feet per second.
Rains (4 months), ...	494,208
Winter (5 months), ...	71,200
Hot weather (3 months), . . .	36,330

The arithmetical mean of these figures for the whole year is, obviously, 203,485 cubic feet per second; which gives us an annual water-discharge of **43.625** cubic miles.

Now, the total length of the Himalayan ridge drained by the Ganges is 670 miles, and the rainfall increases from west to east: but the Ganges, at Ghazipûr, has received the drainage of only 150 miles of the western end of the ridge. Sir Charles Lyell, following Colonel Strachey, proposed to estimate the discharge of the Ganges into the sea by increasing the Ghazipûr discharge, in the proportion of 670 to 150, or to nearly 4½ times the Ghazipûr discharge.*

As this appears to me a very rude method of calculation, I have recomputed the areas of the rain-basins of

* *Principles of Geology* (Lyell), vol. i. p. 480: London (1875).

the Ganges, above and below Ghazipûr; and of the Brahmapûtra, using for the purpose Mr. Stanford's newest Orographical Map of Asia.

I traced carefully, for this purpose, the three areas mentioned, and also the area on the map lying between 20° and 30° latitude, and within 10° longitude.

The tracings were then carefully cut out and weighed, with the following results:—

(1). Rain-basin of Ganges above Ghazipûr (*weight of tracing*) = 0·2265 grm.
(2). Rain-basin of Ganges below Ghazipûr (*weight of tracing*) = 0·2780 „
(3). Rain-basin of Brahmapûtra (*weight of tracing*) . . . = 0·4620 „
(4). Standard area (*weight of tracing*) . . . . = 0·5150 „

I calculated the standard area at 325,660 sq. geogr. miles.* From the above we readily find—

Ganges.

Rain-basin above Ghazipûr	= 143,220	geogr. miles.
Rain-basin below Ghazipûr	= 175,790	„ „
Total, . . .	319,010	geogr. miles.

Brahmapûtra.

Total Rain-basin, ... 292,140 geogr. miles.

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* By integrating the expression $r^2 \sin\theta \, d\theta \, d\phi$ between the limits named, where

r = radius of earth in geogr. miles = $3958 \times \frac{60}{69 \cdot 1}$,

θ = north polar distance,

ϕ = longitude.

This result gives a total discharge for the Ganges somewhat more than double the Ghazipûr discharge (instead of four or five times), or, exactly—

Annual Discharge = **97·170** cubic miles (statute).

The dry season discharge of the Brahmapûtra, at Gwalpara, near the head of its delta, is given by Major Wilcox,* as 150,000 cubic feet of water per second; and I have calculated (by reducing Everest's discharge of 36,330 cubic feet per second, of the Ganges, at Ghazipûr) the Gangetic dry-season discharge at a point corresponding with Gwalpara, on the Brahmapûtra, to amount to 76,000 cubic feet per second.

If we adopt this ratio, we find, for the probable

Annual Water discharge of the Brahmapûtra, ... $= 97{\cdot}17 \times \frac{150}{76}$

= **191·78** cubic miles (statute).

The total annual water-discharge of the Ganges-Brahmapûtra system may be estimated, therefore, at **288·95** cubic miles.†

Sir John Herschel‡ states (without quoting his authority) that the Irawady delivers, on the average of the whole year, into the sea 350,000 cubic feet per second; of which $\frac{1}{3000}$th part by weight is silt. This amounts to an

Annual Water Discharge of Irawady, . . = **75·038** cubic miles (statute).

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* *Asiatic Researches*, vol. xvii. p. 466.

† This, as I shall afterwards show, is much greater than the discharge of the *Mississippi-Missouri* system.

‡ *Physical Geography*, p. 207 : Edinburgh (1869).

Mr. Everest found that, during the rainy season, the mud held in suspension by the water of the Ganges at Ghazipûr amounted, on the average, to $\frac{1}{428}$th part by weight of the water-discharge.

If we neglect the mud carried down by the river during the other eight months of the year, we can find a limit to the rate at which the rain-basin of the Ganges is being reduced by the action of the rainfall.

During the four rainy months the quantity of water passing Ghazipûr is

$$494208 \times 60 \times 60 \times 24 \times 30 \times 4 \text{ cubic feet.}$$

Reducing to cubic fathoms, and multiplying by 6, to reduce to tons,* and dividing by 428, to find the weight of mud, we find

$$\frac{494208 \times 60 \times 60 \times 24 \times 30 \times 4 \times 6}{6^3 \times 428} =$$

$$332{,}550{,}000 \text{ tons of mud.}\dagger$$

We can now estimate the number of years required to scrape off one foot from the whole surface of the Gangetic rain-basin above Ghazipoor, by means of the formula

$$x = \frac{2{,}660{,}000 \times A}{T},\ddagger$$

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* A cubic fathom of water is six tons q.p.

† Sir John Herschel (without quoting his authority) gives 534,600,000 tons as the sea-discharge of the Ganges.

‡ This formula is readily deduced from the following facts :—

1. The mean specific gravity of surface rock is 2·66.
2. A cubic fathom of water weighs 6 tons.
3. A geographical square mile contains 1,000,000 square fathoms.

where x = number of years,

A = area of rain-basin in sq. geogr. miles,

T = annual weight of silt discharged, in tons.

Writing in this formula—

$$A = 143{,}220,$$
$$T = 332{,}550{,}000,$$

we find, for the upper basin of the Ganges,

$$x = 1146 \text{ years.}$$

Or, that *the rainfall of the Upper Ganges scrapes off one foot of rock from the whole surface of its rain-basin in* 1146 *years.* This result is about half that given for the Ganges at p. 94, where the number of years is stated at 2358. My authority for the chief part of the Table in p. 94 was a Paper published by Prof. Geikie,* who does not give the details of his calculations. In all probability Prof. Geikie compared the discharge of mud at Ghazipûr with the whole rain-basin of the Ganges, and so got a doubled result.

If my result be altered in the proportion of the rain-basin above Ghazipûr to the whole rain-basin, we find

$$\frac{1146 \times 319}{143} = 2556 \text{ years,}$$

which does not differ much from Prof. Geikie's estimate.

Whatever may be the explanation of the discrepancy, I feel great confidence in the data from which I have obtained my result; which is important in its bearing on the duration of geological time, which it obviously tends to diminish.

* *Geological Magazine*, vol. v. p. 250.

LECTURE V.*

THE RIVERS AND LAKES OF AFRICA AND SOUTH AMERICA.

LADIES AND GENTLEMEN,

I propose, in this Lecture, to compare the continents of South America and Africa, considered simply as instruments for the manufacture of rivers; a point of view which will serve to impress upon your minds the laws of atmospheric circulation, of rainfall, and of production of rivers, which have been already explained to you.

A river may be defined to be the surplus of rainfall over evaporation, seeking its way down to the sea level, by the *path of least resistance*, which is the path of *greatest slope*, or *valley-line*.

Each river drains an area, called its *rain-basin*, and the boundary lines of the rain-basins are called *water-sheds*,† or lines of *least slope*, or *ridge-lines*.

At the heads of the valleys, the ridge-line, or watershed, is at right angles to the river-line, a circumstance that enables us to trace, accurately, the rain-basins on any map whose rivers are correctly drawn.

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* This Lecture was delivered on the 1st April, 1876.

† This word strictly means *water-partings*, but is sometimes, erroneously, used as identical with *rain-basins*.

The conditions to be fulfilled by a continent, for the successful manufacture of rivers, are the following:—

1. *An abundant supply of aqueous vapour, brought by the prevailing winds.*

2. *The continent should have an area sufficiently large for its rainfall to feed great rivers.*

3. *A range of mountains sufficiently high to precipitate all the aqueous vapour, at right angles to the prevailing winds, and placed on the leeward side of the continent.*

Let us now compare South America with Africa in these three respects:—

I.—*The Supply of Aqueous Vapour.*

The whole of Africa, down to 28° south latitude, lies within the limits of the Trade Winds, which extend from 35° N. to 28° S. (page 102). This part of the continent has therefore an abundant supply of aqueous vapour carried from the Indian Ocean by the easterly Trade winds. The latitudinal width of this part of Africa is 63°, or 3780 geographical miles.

South America, on the contrary, extends northwards, only 10° north of the equator—thus losing the rainfall of the Trade Winds, from 10° N. to 35° N. (which falls upon the West Indies, Mexico, and the Southern States of America). South America, therefore, enjoys the Trade Wind rainfall of a range of 38° of latitude only, or 1480 geographical miles, as compared with 63° of latitude, or 3780 geographical miles, enjoyed by Africa.

II.—*The Size of the Continents.*

Africa has an area of 11,300,000 miles*, square; while South America possesses an area of 6,800,000 miles only.

III.—*Situation of the Condensing Ranges.*

When we consider, however, the situation of the mountain chains that condense the Trade Wind vapours into rain, we shall see that the advantage is altogether on the side of South America.

In Fig. 26 we have an Orographical Map of Africa, showing flat plains in the north and north-west; an elevated table-land in the south, and lofty mountain chains running north and south on the east coast near the equator, continuous and more or less broken, down to the Cape of Good Hope. Now, it is to be remembered that the Trade Winds are easterly, and bring in the aqueous vapour from the Indian Ocean.

A great quantity of this vapour is condensed by the equatorial mountain chain, running north and south, and including the famous mountains *Kenia* and *Kilima-Ndjaro*†; but the rain, so condensed, falls on the eastern slope of the mountain chain, and so runs back again into the Indian Ocean, without having had time or opportunity for manufacturing large rivers.

The equatorial meridian chain has so effectually robbed the eastern Trade Winds of their vapour, before crossing the ridge, that (notwithstanding the continuance of the rains during the entire year) the annual rainfall of the Equatorial lake region is estimated by Captain Speke at only 49 inches.

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* Statute.

† Page 28.

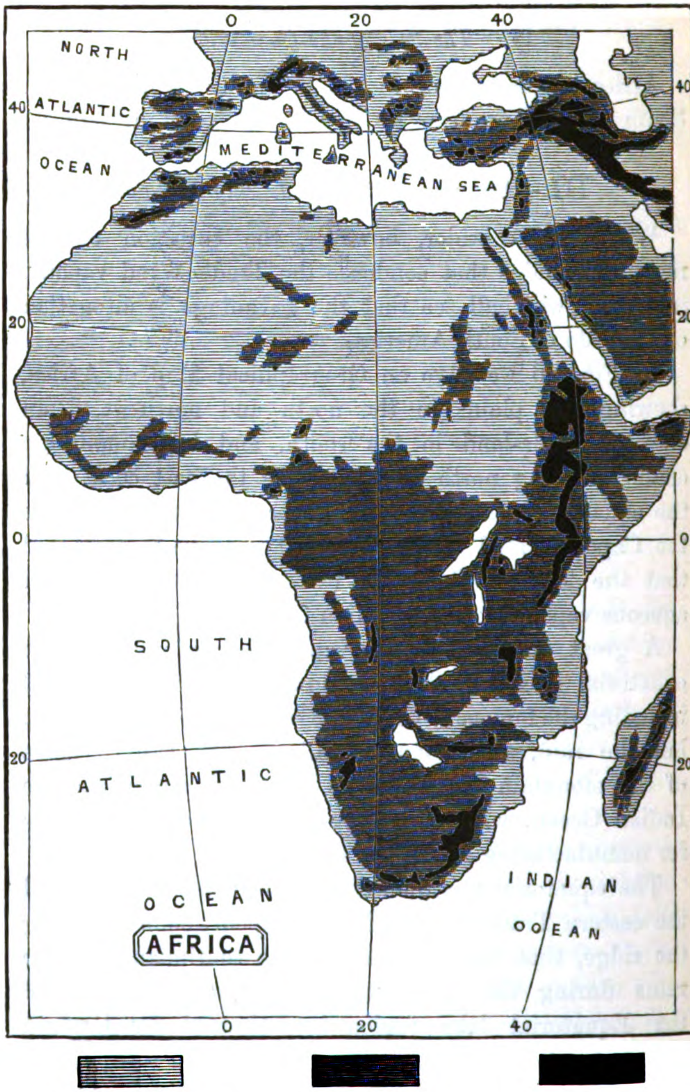
NORTH
ATLANTIC
OCEAN
MEDITERRANEAN SEA
SOUTH
ATLANTIC
OCEAN
AFRICA
INDIAN
OCEAN
0
20
40
Sea level to half a mile.
Half a mile.
Above one mile.

Fig. 26.


SOUTH AMERICA
SOUTH
PACIFIC
OCEAN
SOUTH
ATLANTIC
OCEAN
80
60
40
20
0
20
40
60
120
100
80
60
40
20
0
Sea level to half a mile.
Half a mile.
Above one mile.

Fig. 27.

When we bear in mind that at Zanzibar, on the east coast, in the same latitude, the rainfall equals 100 inches in the three months March, April, and May alone, we may conclude that the Kenia ridge has deprived the Equatorial lakes of fully one-half of their natural rainfall supply.

In Fig. 27 we have a corresponding Orographical Map of South America, showing a striking contrast to that of Africa.

The meridional chain, nowhere less than a mile in height, extends along the western coast, through the entire length of the continent. The easterly Trade Winds blow across the continent, and all the rainfall, before reaching the chain of the Andes, must flow back again into the Atlantic in river systems; and, finally, the last traces of vapour are extracted from the Trade Wind by the lofty mountain chains that guard the western coasts. And so effectually is this task accomplished, that in Peru, on the western side of the Andes, there is a rainless district,* or desert region, rivalling on a lesser scale the bare and repulsive features of the Sahara in Africa.

In order to show, at a glance, the great superiority of South America over Africa, in the manufacture of rivers, I shall contrast the La Plata and the Nile.

The rain-basin of the La Plata river system has an area of 968,000 sq. geogr. miles; and I have computed the rain-basin of the Nile (including all the recent discoveries), by a method similar to that used for the Ganges and Brahmapûtra, to be 1,049,000 sq. geogr. miles—so that the Nile basin is rather the larger.

* Celebrated for its mineral beds of Nitrate of soda, and Borates of lime and soda, occurring at the surface of the ground, and preserved by the total absence of rain.

When we compare the annual water-discharge of the two rivers, we find an astonishing difference.

Mr. J. F. Bateman, in his report on the proposed harbour of Buenos Ayres, fixes the December low-water discharge of the River Plate at 670,000 cubic ft. per second. Converting this into cubic miles per annum, we find—

Minimum annual discharge of the River Plate, } 143·64 cubic miles.

The actual discharge will be, of course, much greater than this.*

Sir John Herschel states, on the authority of Talabot, that the mean discharge of the Nile, on the average of the whole year, is 101,000 cubic feet per second; or 21·654 cubic miles.†

We thus see, taking into account both the discharge and the rain-basin, that the La Plata surface of South America exceeds the Nile surface of Africa, in river-making power, much in the proportion of, for equal surfaces, more than

$$\frac{14364}{2165} \times \frac{1049}{968} = 7{\cdot}19,$$

or that South America has much more than seven times greater river-making power than Africa, comparing equal surfaces.

The extraordinary poverty of north and north-eastern

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* *Vide* Note A.

† In Note B to this Lecture, I have given a new calculation of the Nile discharge, from which I obtain 25·49 cubic miles per annum, which appears to be as reliable as Talabot's estimate.

Africa in river-producing power is well shown in Fig. 28, which represents the four chief rivers of Africa, viz., the Nile, the Niger, the Congo, and the Zambesi; the shaded

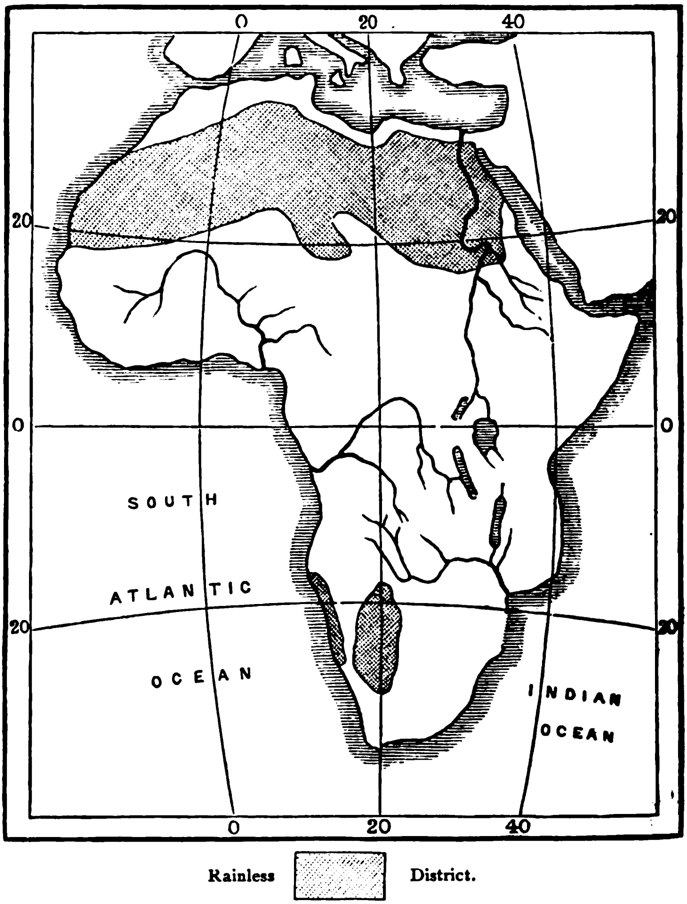

Fig. 28.

portion showing the rainless districts, viz., the Sahara Desert in the north, which is estimated at 2,500,000 sq.

miles, or thrice the size of the Mediterranean; and the Kalahari Deserts in the south, the home of the Bushmen, and famous for the water-secreting tubers buried beneath the surface of the soil.

The Nile.—The Nile and its valley possess for us an interest such as no other river-basin has; the antiquity and civilization of its people, and their intimate connexion with the records of the Jewish race, and consequently with our own Christian traditions, give it a claim upon our study greater even than that of the rivers and rain-basin of Mesopotamia.

To the Ancients the Nile appeared almost miraculous; its floods have a Classic renown. Everyone knows that Egypt is very fertile, notwithstanding the excessive dryness of its climate, and that it is annually fertilized by the inundation, which has acted for 3000 years without interruption, and that probably for 10,000 years no change of physical conditions has occurred in the gigantic basin of this river, which occupies an area of 1,049,000 sq. geogr. miles.

I shall introduce to you this wonderful river in the words of Herodotus, which are ever fresh and young:—

"What they said of their country seemed to me very reasonable. For, anyone who sees Egypt, without having heard a word about it before, must perceive, if he has only common powers of observation, that the Egypt to which the Greeks go in their ships is *an acquired country, the gift of the river.** The same is true of the land above the lake to the distance of three days' voyage, concerning which the Egyptians say nothing, but which is exactly the same kind of country.† . . . .

* *ὅτι Αἴγυπτος, ἐς τὴν Ἕλληνες ναυτίλλονται, ἔστι Αἰγυπτίοισι ἐπίκτητός τε γῆ καὶ δῶρον τοῦ ποταμοῦ.*

† Herodotus, Bk. ii. 5.

"One fact which I learned of the priests is to me a strong evidence of the origin of the country. They said that when Moeris was king, the Nile overflowed all Egypt below Memphis, as soon as it rose so little as eight cubits. Now, Moeris had not been dead 900 years at the time when I heard this of the priests; yet, at the present day, unless the river rise sixteen, or at the very least fifteen cubits, it does not overflow the lands. It seems to me, therefore, that if the land goes on rising and growing at this rate, the Egyptians who dwell below Lake Moeris in the Delta (as it is called) and elsewhere will one day, by the stoppage of the inundations, suffer permanently the fate which they told me they expected would sometime or other befal the Greeks. On hearing that the whole land of Greece is watered by rain from heaven, and not, like their own, inundated by rivers, they observed: 'Some day the Greeks will be disappointed of their grand hope, and then they will be wretchedly hungry'; which was as much as to say, 'If God shall some day see fit not to grant the Greeks rain, but shall afflict them with a long drought, the Greeks will be swept away by a famine, since they have nothing to rely on but rain from Jove, and have no other resource for water.'

"And certes, in thus speaking of the Greeks, the Egyptians say nothing but what is true. But now let me tell the Egyptians how the case stands with themselves. If, as I said before, the country below Memphis, which is the land that is always rising,* continues to increase in height at the rate at which it has risen in

* *αὕτη γάρ ἐστι ἡ αὐξανομένη*. This is not correct, for the whole Nile valley is rising, and rises faster as we ascend the river. Thus the mean thickness of the mud deposit in the delta is only 18 feet; in middle Egypt it is 30 feet; and in upper Egypt 40 feet.

times gone by, how will it be possible for the inhabitants of that region to avoid hunger, when they will certainly have no rain, and the river will not be able to overflow their corn lands? At present, it must be confessed, they obtain the fruits of the field with less trouble than any other people in the world, the rest of the Egyptians included, since they have no need to break up the ground with the plough, nor to use the hoe, nor to do any of the work which the rest of mankind find necessary if they are to get a crop; but the husbandman waits till the river has of its own accord spread itself over the fields and withdrawn again to its bed, and then sows his plot of ground, and after sowing turns his swine into it—the swine tread in the corn—after which he has only to await the harvest. The swine serve him also to thrash the grain, which is then carried to the garner.* . . . . .

"Concerning the nature of the river, I was not able to gain any information either from the priests or from others. I was particularly anxious to learn from them why the Nile, at the commencement of the summer solstice begins to rise, and continues to increase for a hundred days—and why, as soon as that number is past, it forthwith retires and contracts its stream, continuing low during the whole of the winter until the summer solstice comes round again.† On none of these points could I obtain any explanation from the inhabitants,

* Herodotus, Bk. ii. 13, 14.

† The inundation becomes sensible at Cairo in the first days of July, and about the 15th August the river reaches nearly half its maximum height, which is finally attained from the 20th to the 30th September; it then remains in a sort of equilibrium for 15 days, after which it decreases much more slowly than it rose: on the 10th November the river again reaches half its maximum height, and the true inundation ends with the month of November.—Elie de Beaumont, *Leçons de Géologie pratique*, tom. ii. p. 203.

though I made every inquiry, wishing to know what was commonly reported—they could neither tell me what special virtue the Nile has which makes it so opposite in its nature to all other streams,* nor why, unlike every other river, it gives forth no breezes from its surface."†

Herodotus then discusses at length four theories to account for the inundations of the Nile, the last of these theories being his own:—

1°. The inundation of the Nile is due to the N.W. winds which blow in the valley of Egypt in spring and summer, these winds being supposed to retard the river, and so cause the floods.

---

* This specially refers to the mysterious origin of the Nile, without rainfall, sent direct from Heaven, like the meteoric stone which was worshipped in the temple of Artemis at Ephesus—

> Πρίν γ' ὅτ' ἂν Αἰγύπτοιο διϊπετέος ποταμοῖο
> Αὖτις ὕδωρ ἔλθῃς, ...
>
> —*Odys.* iv. 477, 8.

But it also refers to the peculiar properties of the Nile water, and to the fertilizing power of its mud. Although very wholesome, the water of the Nile disagrees for a few days with strangers; and this property is attributed by Athenæus to the *nitre* it contains (*Deipn.* ii. 41). This is confirmed by modern discoveries, which have proved that the inundation of the Nile and its fertilizing mud are brought down by the summer tropical rainfall from the Abyssinian Highlands, by means of the Blue Nile and Atbarah rivers; while the steady, constant, everyday flow of the river is supplied from the Victoria Nyanza Lake (to which the Albert Nyanza acts as a mere backwater) by means of the White Nile.

The Abyssinian Mountains consist largely of limestone covered by tabular trap, which, as usual, contains abundant zeolites; these are rapidly dissolved and decomposed by the heavy rains of the tropical summer, thus supplying to the mud of the inundation an amount of potash and soda salts, that make it almost equivalent to an artificial manure. On the other hand, the White Nile, being merely the quiet overflow of the Equatorial lakes, brings down nothing but a slight solution of decayed vegetable tissues.

† This is unintelligible.

2°. The Nile behaves so strangely because it flows from the ocean, and the ocean flows all round the earth.

3°. The inundation of the Nile is caused by the melting of snows.*

4°. The opinion of Herodotus himself (so, at least, I understand him) is, that it is not so much the floods of summer that require explanation, as the low water of the remainder of the year; and, regarding the Sun, as a Meteor, or Atmospheric Fire Ball, he supposes, that being driven in winter out of his proper course by storms, he vaporises the remoter sources of the Nile, and so causes the low water. He says:—

"Perhaps after censuring all the opinions that have been put forward on this obscure subject, one ought to propose some theory of one's own. I will therefore proceed to explain what I think to be the reason of the Nile's swelling in the summer time. During the winter the Sun is driven out of his usual course by the storms, and removes to the upper parts of Libya. This is the whole secret in the fewest possible words; for it stands to reason that the country to which the Sun-god approaches the nearest, and which he passes most directly over, will be scantest of water, and that there the streams which feed the rivers will shrink the most." †

Further on, he illustrates his explanation by an imaginary case applied to the Danube:—

"Were the positions of the heavenly regions reversed,

* Although the melting of the snows of Kenia and Kilima-ndjaro must aid the summer floods, their chief cause is, of course, the tropical summer rainfall.

† Herod. ii. 24.

so that the place where now the north wind and the winter have their dwelling became the station of the south wind and of the noonday, while, on the other hand, the station of the south wind became that of the north, the consequence would be that the sun, driven from the midheaven by the winter and the northern [*now supposed southern*] gales, would betake himself to the upper parts of Europe, as he now does to those of Libya, and then I believe his passage across Europe would affect the Ister exactly as the Nile is affected at the present day."*

The Blue Nile (*Bahr el Azrek*) and the White Nile (*Bahr el Abiad*) unite their streams at Khartoum, from which place to the delta, a distance of 1243 miles, the Nile does not receive the waters of a single brook, with the exception of the Atbarah, which joins it about 200 miles below Khartoum.

Now, since Nubia and Egypt are countries where it scarcely ever rains, where water springs are very scarce, and where evaporation is very rapid, the volume of the Nile diminishes rather than increases as it approaches the sea.

Egypt must be regarded merely as a valley through which the waters of the Nile flow, and which separates two vast countries completely sterile.

This valley, with the exception of the delta, is closed in between two chains of mountains of moderate height, not merely uncultivated, but absolutely bare from base to summit. The eastern, or Arabian chain, is composed of granite rocks, flanked with sedimentary deposits, of the cretaceous and nummulitic periods. The western, or Libyan chain, is merely the escarpment edge of the

* Herod. ii. 26.

plateau of the Sahara Desert. The Nile, as it flows between these barren hills, forms a long narrow ribbon of verdure on each side, from the Tropic of Cancer to the Mediterranean.

The form of the Nile delta is shown in Fig. 29, where the distance between the Rosetta and Damietta mouths is 90 miles, and the sea face of the whole delta nearly 200 miles. From the head of the delta at Cairo or Memphis to the sea front is 100 miles.

According to Sir J. G. Wilkinson, the alluvial matter formed in 1700 years on the land near Elephantiné, at the first cataract, Lat. 24° 5′, is about 9 feet in thickness (or at the rate of 6·35 inches per century); at Thebes, Lat. 25° 43′, it is about 7 feet in the same time (or at the rate of 4·94 inches per century); at Heliopolis and Cairo, Lat. 30°, about 5 feet 10 inches (or at the rate of 4·12 inches per century).

From the measurements of mud deposit made on the gigantic statue of Rameses (the middle of whose reign was about 1361 B.C.), it has been computed that in 3211 years an accumulation of 9 feet 4 inches of mud had formed (or at the rate of 3½ inches per century). Now, borings made under the superintendence of Mr. Horner, at this place, showed that the Nile mud deposit rested on the sand of the desert at a depth of 32 feet; this deposit being formed before the time of Rameses. From this it follows, if the rate of deposition had remained constant, that the Nile delta must be between 13000 and 14000 years old.

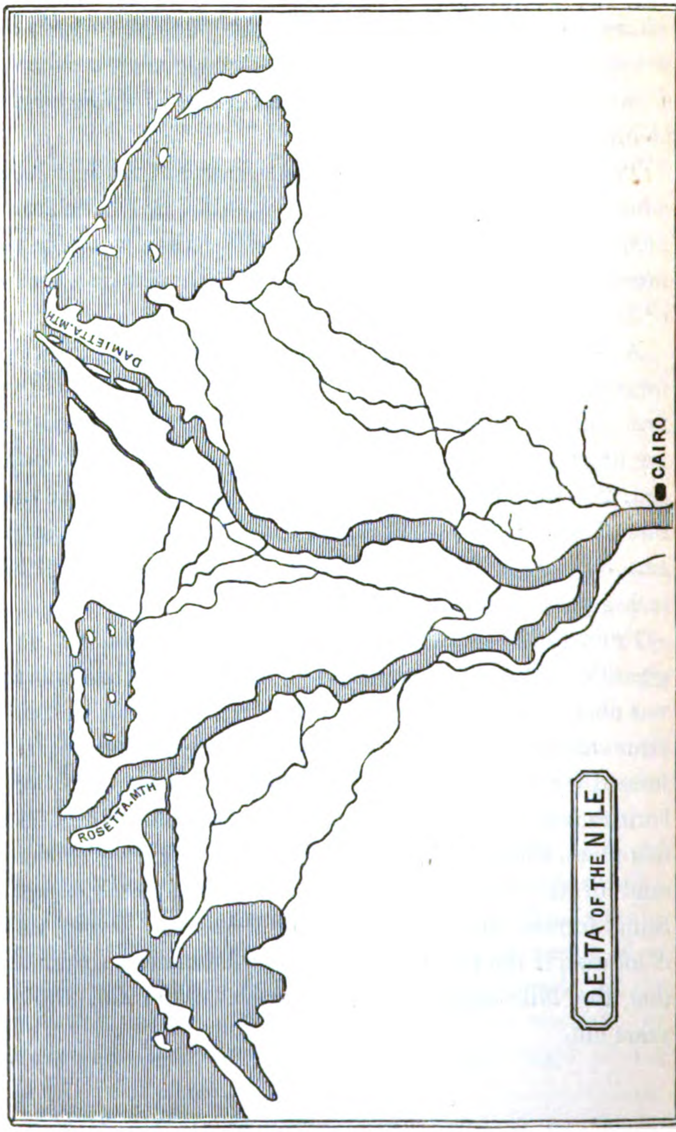

Fig. 29.

The Equatorial Lakes of Africa, and their River Systems.—Between 4° N. Lat. and 15° S. Lat. a collection of great lakes has been discovered in Eastern Africa. These lakes give rise to three of the four great rivers of Africa, viz.:—the Nile, the Congo, and the Zambesi.

Nile Basin.

	Area.	Height.
1. Lake Victoria Nyanza,	21,500 sq. m.	4,168 ft.
2. Lake Albert Nyanza, .	1,620 „	2,720 „
3. Lake Dembea, . . .	1,020 „	6,100 „

Congo Basin.

	Area.	Height.
1. Lake Tanganika, . .	9,240 sq. m.	2,756 ft.
2. Lake Bangweola, . .	—	3,688 „
3. Lake Mweru, . . .	—	3,000 „
4. Lake Kassali, . . .	—	1,750 „

Zambesi Basin.

	Area.	Height.
Lake Nyassa, ...	12,000 sq. m.	1,300 ft.

African travellers have compared this Lake system with that of the St. Lawrence lakes, in North America; with how little reason will be seen from the following summary of the North American lakes:—

St. Lawrence Lakes.

	Area.	Height above sea-level.	Mean depth.
	Square Miles.	Feet.	Feet.
1. Lake Superior, . .	32,000	630	900*
2. Lake Michigan, .	22,400	600	1000*
3. Lake Huron, . .	20,400	600	1000*
4. Lake Erie, . . .	9,600	565	120
5. Lake Ontario, . .	6,300	234	530*

In a similar spirit of exaggeration, African explorers have rashly ventured to compare African rivers with those of North and South America. I have already shown how inferior the Nile is to the La Plata.

Cameron thus writes of the *Lualaba*, a southern branch of the Congo (at Nyangwé) :—

"This great stream must be one of the head waters of the Kongo, for where else could that giant among rivers obtain the 2,000,000 cubic feet of water which it unceasingly pours each second into the Atlantic?† The large affluents from the north would explain the comparatively small rise of the Kongo at the coast; for since its enormous basin extends to both sides of the equator, some

* It will be observed that the bottoms of these lakes are far below the sea-level. It has been calculated that the St. Lawrence lakes form more than half the whole fresh water of the globe.

† This would amount to 428.8 cubic miles discharge in the year; which is highly improbable.

portion of it is always under the zone of rains, and therefore the supply to the main stream is nearly the same at all times, instead of varying, as is the case with tropical rivers, whose basins lie completely at one side of the equator."*

Source of the White Nile.—The White Nile takes its origin in a gigantic boggy plain or moss, exactly 4000 feet above the sea level, called the *Nya Kun Swamp*, and the rain that falls on this gigantic moss, at Lat. 5° 45′ S. and Long. 34° 40′ E., is at a loss to know whether it is destined to travel northward towards the Mediterranean, through the sluggish *Lewumberi* river, into the Victoria Nyanza and White Nile; or eastward towards the Indian Ocean, through the rapid *Mdabura* river into the Rufiji; or westward towards the Congo and Atlantic Ocean, through the flooded, five-branched *Nghwàla* river (River of Partridges), by the *Malagarazi* and Lake Tanganika.

The most southern source of the White Nile is the river Lewumberi, which, changing its name into the *Shimeeyu*, enters the Victoria Nyanza in its south-eastern gulf, called, after the name of the discoverer of the Victoria Lake, *Speke Gulf.*

In the year 1856, Lieut. Speke, a young officer of the Indian army, who had distinguished himself in the campaigns of Lord Gough, joined Lieut. Burton to

* This explanation almost rivals Herodotus in ingenuity, but is entirely erroneous, for the rain-basin of the Congo (which I estimate at 856,800 sq. geogr. miles) lies almost altogether to the south of the equator; and its equable flow (like that of the White Nile) is to be explained by the great lake system through which it passes, and which acts (as lakes do everywhere) as a regulator of the river discharge.

explore the Somali country on the Gulf of Aden. In the following year the two explorers started from Zanzibar to visit the "Mountains of the Moon" described by Ptolemy, and to seek a large inland sea which was believed to exist in that part of Africa, and which was reputed to be as large as the Caspian Sea.

During this expedition Burton and Speke discovered Lake Tanganika, and Speke discovered the great lake, called by the Arabs the *Ukerewé Sea.* Speke came to the conclusion that this great lake was the source of the White Nile, and named it the Victoria Nyanza.

In 1858, Speke and Grant revisited the Victoria Nyanza, and tracked the source of the White Nile from the Lake to Gondokoro, where they met Baker and his party on the 15th February, 1863, who had just completed the exploration of the sources of the Blue Nile in Abyssinia, and was then on his way to the south, in search of Speke and Grant, of whom nothing had been heard for three years. While Speke and Grant returned home, Baker went south, and completed Speke's discoveries by exploring the Albert Nyanza.

The course of the Upper Nile is as follows:—Flowing from the northern end of the Victoria Nyanza, as the Victoria Nile, it passes over the Ripon Falls, a few miles after leaving the lake, and then proceeds in a north-westerly direction towards the Albert Nyanza, which it enters, after passing over the Murchison Falls, a few miles above its outlet. The White Nile issues from the southern end of the Albert Nyanza Lake, and then flows 3000 miles further before it joins the Mediterranean.

The total length of the Nile may be thus estimated:—

(1). *Nile proper*— From Mediterranean to junction of White Nile and Blue Nile (Khartoum), ...	1243 miles.
(2). *White Nile*— From Khartoum to south end of Albert Nyanza Lake, ...	1757 ,,
(3). *Victoria Nile*— From outlet of Albert Nyanza to outlet of Victoria Nyanza, . .	290 ,,
(4). *Victoria Nyanza Lake*— From outlet of Victoria Nile to inlet of Shimeeyu river in Speke Gulf, ...	225 ,,
(5). Length of Shimeeyu and Lewumberi rivers from Victoria Nyanza to Watershed at the Nya kun Swamp,	300 ,,
Total, ...	3815 miles.

The Nile is therefore one of the longest rivers in the world; the order being—

	Length.
1. Missouri, ...	4096 miles
2. Nile, ...	3815 ,,
3. Amazon, ...	3545 ,,

If these three rivers were joined on, as a single stream, it would reach nearly half way round the globe.

A large lake, called by the natives *Muta-nzige*, lies to the south of the Albert Nyanza Lake, and was visited on its eastern shore by Stanley, at a gulf named by him Beatrice Gulf. He estimated the width of the Muta-nzige at this place at 15 miles, and to the north of the gulf the Gordon Bennett Mountain rises to a height of 15000 feet. Mr. Stanley supposes that this lake may be connected with the Albert Nyanza, which appears to be improbable, as the water-discharge of the Albert Nyanza into the White Nile does not seem much to exceed the water-discharge of the Victoria Nile at the Murchison Falls into the Albert Nyanza Lake.

The Congo River.—The discoveries of Livingstone, Cameron, and Stanley have made us largely acquainted with the remarkable lake and river systems that ultimately form the Congo, which enters the Atlantic at 6° S. Lat., after describing a long curved course, north-west, west, and south-west.

It is highly probable that Lake Tanganika is one of the sources of the Congo, for as its waters are always fresh, it must have an outlet; and although Stanley has not confirmed Cameron's idea that the *Lukuga* river or creek (which opens on the middle of the western shore of Lake Tanganika) is the connecting link; yet it is extremely probable that at flood times Lake Tanganika discharges its superfluous waters into the southern branch of the Congo, known as Webb's Lualaba. It is also probable that the Lakes Muta-nzige and Alexandra discharge into some branch of the same river.

The following systems of lakes certainly form its source. At the end of April, 1872, Livingstone died in a solitary hut near a small native village called Ilala, on the southern shore of Lake Bangweola. The mountains of Lokinga, close to the scene of Livingstone's death, from the southern watershed of Lake Bangweola (12° S. Lat., Long. 30° E.), which is the source of Webb's Lualaba, as the Congo is called in the upper part of its course. The *Chambesi* river flows from the north-east into Lake Bangweola, and may be regarded as the source of this part of the Congo river-system. From Lake Bangweola, Webb's Lualaba flows northwards, passing through Lake *Mweru*, and continues its northerly course to 6° S. Lat., where it is joined by the river *Kamarondo*, which also takes its origin in the mountain ranges at 12° S. Lat., Long. 25° W.; the Kamarondo flows, like Webb's Lualaba, through two lakes in its course before it joins Webb's Lualaba, viz., Lake *Lohemba* and Lake *Kassali*.

From the junction of Webb's Lualaba and the Kamarondo in 6° S. Lat., the Lualaba or Congo flows to the north-west, passing Nyangwé, Lat. 4° 15′ S., on its way.

Nyangwé is a large settlement of Arab traders, and has a lively and well-attended market, held each fourth day. It was visited by Livingstone, Cameron, and Stanley, and the latter started from near Nyangwé on his celebrated voyage down the Congo to the west coast of Africa.

Cameron estimates the width of the Congo at Nyangwé at 1020 yards, and it abounds in crocodiles and sea cows. He measured the water-discharge at the dry season, and found it to be 126,000 cubic feet per second.*

* The low-water discharge of the Nile proper is only 8000 cubic feet per second, its high-water discharge being 160,000 cubic feet per second. If we compare Cameron's estimate of the dry season water-discharge of the Congo at Nyangwé with Everest's estimate of the low-water discharge of the Ganges at Ghazipûr, or with the estimate of the Nile low-water discharge, made by the French expedition, 1799–1801; we should conclude

Stanley does not estimate the water-discharge at Nyangwé, but gives the following measurements of its cross section at its lowest level. It consists of three channels, separated by two islands in the central part of the river :—

	Width.	Mean Depth.
1st Channel, . .	800 yds. . .	18·75 ft.
2nd „ . .	275 „ . .	12·50 „
3rd „ . .	250 „ . .	11·00 „

and he records that the water in the second and third channels has a slightly quicker flow than in the main channel.

The river *Ruiki* joins the Congo some miles below Nyangwé from the south. At this point, on the 22nd of November,* Stanley estimated the current of the Congo at $1\frac{3}{4}$ knots per hour, and its width at 1200 yards. The cross section of the Congo, at Nyangwé, just stated, amounts to 63,562 sq. feet. This, with the above current, would give a water-discharge equal to 185,400 cubic feet per second. It clearly appears from the foregoing estimates that the Congo is a much larger river than the Nile; for its low-water discharge at Nyangwé is equal to the high-water discharge of the Nile at Cairo.

I estimate the rain-basin of the upper Congo, above Nyangwé, at 249,500 sq. g. miles.

If we adopt Cameron's low-water discharge at Nyangwé, and assume an equal rainfall all over the rain-basin, we find that the low-water discharge of the Congo into the Atlantic will amount to 432,700 cubic feet per second.†

that the Congo at Nyangwé is $3\frac{1}{2}$ times greater than the Ganges at Ghazipûr, and 16 times greater than the Nile at Cairo.

* April, May, June, and the first part of July, are the season of floods.

† The area of the whole Congo basin is 856,800 sq. geo. miles.

Comparing this with the corresponding measured low-water discharge of the La Plata into the Atlantic, we find the Congo discharge to be two-thirds of that of the La Plata, while the rain-basin of the Congo is about seven-eighths of that of the Plate.

From Nyangwé to the Atlantic, the Congo flows 1600 miles, at first north-westerly, then westerly, attaining a latitude 2° N., and finally south-westerly.

During this long course it receives many large tributaries on both sides, which may be thus enumerated, omitting the lesser streams and the doubtful rivers:—

Left Bank.	Width.	Right Bank.	Width.
(1). The *Ruiki*,	100 yds.		
		(1). The *Lira*,	300 yds.
(2). The *Kasuka*,	100 „		
		(2). The *Urindi*,	500 „
		(3). The *Lowwa*,	1000 „
(3). The *Lumami*,	600 „		
		(4). The *Leopold*,	100 „
		(5). The *Mbura*,	600 „
		(6). The *Aruwimi*, . .	2000 „
(4). The *Ikelemba*,*	—		
		(7). The *Lawson*,	250 „
(5). *Ibari Nkutu*,	450 „		
		(8). The *Gordon Bennett*,	150 „
		(9). The *Nkenke*,	100 „

* This is the largest river entering from the left hand; its water is tea-coloured, and does not commingle with the main river for 130 miles below its junction. It, possibly, flows through the Lake Lincoln of Livingstone.

The upper course of the Congo from Nyangwé, by Webb's Lualaba, and Lakes Mweru and Bangweola, to the sources of the Chambesi, may be estimated at 900 miles; so that the entire length of the Congo is fully 2500 miles.

River Systems of South America.

From the causes already described, the rivers of South America are the largest and most important in the world, and are so closely connected with each other by low watersheds, that at some future time, without much assistance from engineers, they will make a network of natural navigable channels, forming a system of ship canals extending over the whole continent.

Its remarkable development of navigable rivers would almost seem to compensate South America for its deficiency in coal-beds, which constitute the foundation of the future supremacy of North America.

The more important of the South American rivers, counting from north to south, are—

	Rain-Basin.	
1. The *Orinoco*, . . .	252,000	sq. g. miles.
2. The Amazons, . .	1512,000	„
3. The *Tocantins*, . .	285,000	„
4. The La Plata, . . .	968,000	„

Of these rivers, the Amazons and the La Plata are the largest in the world.

The Orinoco.

This river rises in the southern part of the Parimé Mountain chain, represented in Fig. 27 as stretching east and west. It then runs west, and afterwards north round the flank of the Parimé chain, and is soon joined by the *Guaviare* and *Meta* rivers, flowing eastwards from the Andes range to the southward of Santa Fé de Bogota. After being joined by the Meta, the Orinoco flows eastwards, a broad, navigable river to its delta. The Orinoco, and its branch the Meta, are navigable all the year round for 1000 miles for a fleet, from the mouth of the delta to within 45 miles of Santa Fé de Bogota near the feet of the Andes. The Meta rises at so great an elevation in the Andes, that Humboldt says the vegetable productions at its source differ as much from those of its confluence with the Orinoco as the vegetation of France differs from that of Senegal.

The upper part of the basin of the Orinoco is one impenetrable forest, and the lower part is composed of the extensive plains called *Llanos*.

The Llanos* occupy an area of more than 150,000 sq.

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* The following interesting sketch of the Llanos of Venezuela is quoted from Don Ramon Paez, a native of the country, in Stanford's *Central America, the West Indies, and South America.* London (1878), pp. 225–232:—

"In order to realise the true character of the Venezuelan steppes or Llanos, we cannot do better than follow the guidance of Don Ramon Paez, a native of this region, who traversed the country from the little town of Macaray to the Llanos or Pampas of the Apuré, a north-western tributary of the mighty Orinoco. His road lay at first through sugar-cane, indigo, and tobacco fields, besides extensive plantations of *bucaral* (Erythrina), beneath whose shade flourishes cacao, the ambrosia of the gods, as it has been called. A small park-like district then brought him to the edge of the Galeros, a chain of hills flanking the old banks of a lake, now forming a steppe overgrown with grass.

"The woods of Venezuela possess a great wealth of noble trees, foremost amongst which is the *Vera* or *Lignum vitæ* (*Zygophyllum arboreum*), spread over the land, and especially along the coast. Its wood is so hard that it turns the edge of the sharpest tools. Very abundant is the *Guayacan*, of the same order as the *Vera*, preferred to most others for carving and cabinet-making. Then there is the beautiful *Alcornoque*, whose shade affords the miles, and are as level as the surface of the sea, and extend 1100 miles from the delta of the Orinoco to the foot of the Andes of Pasto; and frequently there is

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greatest relief to the cattle dnring the summer heats. Brazil wood also (*Cæsalpinia braziletto*) is so common that in many places all the fences are made of this valuable timber.

"Through a *quebrada* or dry ravine Don Ramon reached a completely level country, which, with the exception of a few clumps of fan-leaved palms, was covered entirely with a short grass.

"A dense mass of vapour pervading the atmosphere obscured the horizon, while the fan-palms, seen from afar, appeared like ships enveloped in a fog. Gradually the circle of the heavens seemed to close around the traveller, until he became, as it were, encompassed by the sky. He was treading the shores of the great basin of the Llanos, over one of the ancient terraces or *mesas*, which form the borders of these grassy oceans. For three hours he continued his ride over the *mesa* until he reached its border, which commanded an extensive view of the lower-lying savannah. The scene was at once changed into one of the most glorious panoramas in nature. At his feet lay the beautiful expanse of meadow, fresh and smooth as the best cultivated lawn, with troops of horses and countless herds of cattle dispersed over the plain. Several glittering ponds, alive with an immense variety of aquatic birds, reflected from their limpid surface the broad-leaved crowns of the fan-palms, towering above verdant groves of laurel, amyris, and elm-like *robles*. Farther beyond, and as far as the eye could reach, the undulating plain appeared like a petrified ocean after a storm. No description could convey a faithful idea of the reality of the scene—the harmonious effects of light and shade, and the blending of the various tints of green, blue, and purple, dispersed over the extensive panorama—the gentle undulations of the plain—the towering palms gracefully fanning the glowing atmosphere with their majestic crowns of broad and shining leaves. This palm (*Copernicia tectorum*) is a real treasure to the inhabitants of the steppe, and it receives various names according to the uses it is put to. Thus, by the cattle-farmers and settlers it is called the 'thatch-palm' (palma de cobija), because they employ its leaves in thatching their *ranchos;* to the straw-hat makers it is known as the 'hat-palm' (palma de sombrero); and by travellers on the steppe it is termed the fan-palm (palma de abanico), from the use to which they put it as a fan to keep off the flies during a journey. The most beautiful tree of the Llanos, however, is the *saman*, a kind of mimosa, growing in profusion along the not an eminence a foot high in hundreds of square miles. Slight inequalities formed in this vast plain, either by the outcrop of nearly horizontal limestone beds, or by lines

banks of the Apuré and other rivers, which expands aloft, like a gigantic parasol, its crown of delicate feathery foliage. Extensive tracts of land are entirely taken up by this species of tree, and it is impossible, says Don Ramon, to conceive anything more grand in nature than these forests. All along the course of the great rivers Apuré, Guarico, and Portuguesa, the *saman* is found in such countless numbers that the combined fleets of the whole world might be reconstructed from this inexhaustible supply of timber. Equally rank and luxuriant are the grasses in these alluvial lands. Amongst the curious varieties is the *gamelote*, a tall, cutting, and worthless grass, with blades almost as sharp as a Toledo rapier. It grows so closely and rapidly as to obliterate in a few days the paths made by travellers, killing every other species in its way. Unfortunately for the settlers, it is perfectly useless as fodder, except for *chiquires* or water-hogs, which feed on it when nothing better offers, and to the flesh of which it imparts its disagreeable flavour. On the Llanos of the Apuré a singular phenomenon presents itself in the *medanos*, or ranges of low sandhills, which are formed by the loose sand blown by the wind over the boundless plain. They are continually changing—to-day rising above the surface of the surrounding prairies, to-morrow levelled with the dust of the savannahs. But in one district the sandhills, having been overrun by the *gamelote*, which has consolidated the loose masses by its roots, have become a low range of permanent hills, and are called the Medanos de San Martin. This objectionable kind of grass appears, however, to prefer the higher parts of the plain; on the savannahs of the Apuré a luxuriant growth of more tender and succulent kinds characterises the verdant prairie. Some of these grasses are as soft and pliable as silk, and it is owing to the nutritious qualities of the pasture in general that the alluvial plains of the Apuré and its tributaries have become so noted for cattle-breeding. In the upper levels of the Llanos the farmer is compelled to migrate with his stock every summer; on the Apuré the grass is verdant all the year round. Three of the varieties are especially remarkable. One, the *granadilla*—a grass reaching to about four feet in height, with tender, succulent blades, and panicles of seed not unlike some varieties of broom corn—starts with the earliest showers of spring. It grows with great rapidity, and is greedily sought by all ruminants; but, being an annual, it soon disappears, leaving no vestige of its existence. The second is the *carretero*, so named from the beautiful prairie-goose that feeds on it. It has an uninterrupted growth and luxuriance, which of drifted sand, form the watersheds of the various tributaries of the Orinoco and the neighbouring rivers. In the rainy season, from April to October, the tropical rains

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the hot season cannot blast, and grows in the alluvial bottom-lands subject to the periodical inundation. The third—perennial like the preceding—is the *lambedora*, so termed on account of its softness, animals feeding on it appearing to lick rather than masticate it. Cattle and horses thrive on it very perceptibly, and even calves only a fortnight old may be left to shift for themselves amidst these nutritious pastures.

"*Esteros* is the name by which these perennial meadows are designated in Venezuela. The pools and channels of water in these regions of plenty do not dry up in the dry season, and they are consequently the resort of a multitude of quadrupeds and water-fowl. The birds in particular seem to have migrated thither from all quarters of the continent. These prodigious congregations of the feathered tribes are known in the country under the name of *garzeros*, from the many *garzas* or herons predominating in them. The colonies of these birds sometimes extend for several miles. One of the kinds of crane is called the soldier, from its erect bearing and martial air, and is over five feet in height, with a bill fully a foot long. The herons, storks, and ibises are of various sizes and colours—some snow-white, some a delicate blue, others grey or pink, and many a brilliant scarlet. They generally select the spreading top of a low tree, the *caujaro*, growing in vast quantities near the water, in which to build their nests, which are of dry sticks very ingeniously interwoven among the branches. Well-beaten tracks are made under the bushes by the tramp of many suspicious characters of the feline tribe, who make these feathered colonies their favourite resort, and profit by the opportunities of appropriating young birds which fall from their nests. The pools are also the resort of myriads of small ducks, of a kind called *guiriri*, which, when they are disturbed, rise in such incredible numbers as actually for the moment to obscure the sun. They utter a shrill note, resembling the syllables 'gui-ri-ri,' whence their name is derived, so that the hunter easily discovers their whereabouts. Besides these, there are great numbers of a larger duck, the *pato real*, or royal duck, so named probably from a graceful tuft of black feathers with which it is crowned. Here and there a brace of *carreteros* are seen soaring overhead, uttering their peculiar rolling notes; the hoarse quacking of the male bird, followed by the shrill cries of the female, making a perfect resemblance to the rumbling of cart-wheels. During the moulting season, the people in the neighbourhood of these lagoons resort to them from time pour down in torrents, and many hundreds of square miles of the Llanos are inundated by the floods of the rivers. In the dry season, the grass of the Llanos becomes burnt

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to time, and drive without difficulty towards the farm-house as many of these ducks as they may desire.

"This prodigious exuberance of animal life has justly entitled the Apuré to the reputation of being a land of plenty. But it has also its dark side, in the number of noxious species which it cherishes, and in the miasmas which are exhaled from its extensive marshes, which at certain seasons of the year render this fine country almost uninhabitable for man. These marshes are the abode of the enormous water-snake, the *Anaconda*, known in Venezuela under the name of *culebra de agua;* and the woods harbour the boa-constrictor, termed *traga venado*, from the ease with which it gorges itself with a whole deer at one time. Besides wild animals, such as deer, capybaras, and so forth, these great snakes cause havoc among the herds of the Llano farmers; calves, heifers, and colts falling an easy prey should they incautiously step into these treacherous pools. The noxious exhalations of the marshes are injurious to health only in the rainy season: during the dry season strong breezes prevail, which clear off the moisture from the low grounds, and nothing but the recklessness with which the inhabitants expose themselves prevents them from enjoying perfect health during this delightful portion of the year. The jaguar is common in many parts of the Apuré district, and alligators swarm in the rivers; besides which, numerous venomous snakes of various species, including the rattlesnake and the dreaded *lachesis*, lie concealed by the side of pathways in meadows and thickets. The vegetable world has also its subtle dangers in the shape of poisonous herbs and trees. Most common of all is the *Guachamacá*, belonging to the family *Apocyneæ*, or Dogbanes, a group of plants especially distinguished for its fatal qualities. The poison of the *Guachamacá* is so powerful that meat, roasted on spits made from the wood, absorbs poison sufficient to cause the death of all who partake of it. Lastly, the waters of the Llanos furnish their quota of obnoxious creatures, besides the delicious fresh-water turtle and numerous kinds of edible fish. First of all is the sting-ray, which is armed near the end of its tail with a spine several inches long, with which it can inflict a painful wound in the foot of the incautious bather. Next to this is the grotesquely-shaped fish, the *payara*, the upper jaws of which are furnished with a pair of fangs similar in shape to those of the rattlesnake; and the less dangerous electric eel, which abounds in the slimy bottoms of still pools, and is able to administer a stunning shock to horses, especially when entering such pools to quench up, and destructive conflagrations, extending over enormous areas, are common.

Casiquiare.—At 150 miles from its source, in a southern spur of the Parimé mountain chain, a phenomenon occurs in the Orinoco*, which is unique in river systems. The river bifurcates, the main river flowing on towards the north-west, but sending off a large navigable branch to the south, called the *Casiquiare*, which crosses the watershed of the Amazons, and after a course of 150 miles

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their thirst. Worst of all is the last we shall mention, the fish called *caribe*. It resembles in general form the gold-fish, but is a little more corpulent, and has a truculent-looking bull-dog head, with projecting lower jaw. With its powerful and sharp three-edged saw-like teeth it is able to bite in two a strong steel fish-hook ; and it seems to scent blood from afar, judging from the shoals which will rapidly congregate round a wounded animal in the water. Even the armoured alligator is not secure against this redoubtable pest of Venezuelan rivers ; for when blood is drawn in the frequent contests which occur between the males of these formidable reptiles, vast multitudes of the *caribe* rush in and enlarge with their voracious teeth the wounds that have been opened. Besides alligators, there is a species of the true genus crocodile † in the waters of the Orinoco. Another common animal on the Llanos is the wild hog, which is not an indigenous species, but the common domestic hog run wild. It occurs in vast numbers in some parts of this great region, and causes at times great damage to the farmers by tearing up the soil in the best parts of the pasture land, destroying the nutritious grasses, and causing a rank and useless vegetation to spring up in their place."

* It is to be remembered that as the Orinoco rain-basin lies to the north of the Equator, its highest floods occur in August; while the floods of the Amazons occur in March, as its chief rain-basin lies to the south of the Equator. In consequence of this, steam-boats in the future will ascend one river and descend the other river, with ample water, by choosing the proper time of year for each river. The Casiquiare, which forms the natural canal between the Orinoco and the Amazons, is as large (at flood-time) as the Rhine, and flows at the maximum rate of 8 knots per hour.

† This is doubtful.

in a south-westerly direction, joins the *Rio Negro*, a northern feeder of the great water system of the Amazons river.

The Amazons River-system.*—The largest river in the world takes its most remote origin among the Andean Highlands, in a little inky tarn, situated in Lat. 10° 15′ S., Long. 76° 10′ W., lying at an altitude of 14,170 feet above the sea level, to the east of Mount Vilcanota (17,525 feet), and to the north of the great sacred Lake Titicaca, which lies between the eastern and western Cordilleras of the Andes, at an elevation of 12,196 feet above the sea level. This remote and elevated mountain lake reminds us of the sacred lakes from which the Brahmapûtra and Suttlej derive their origin;† but it possesses physical features which are, perhaps, unparalleled in river systems. It gives origin to two rivers which flow from it (as part of a common watershed) into two totally distinct rain-basins and river-systems.

1°. To the south flows a stream which soon becomes the river *Pacura*, which, after a course of 100 miles, flows into the northern end of Lake Titicaca. This lake is the largest body of fresh water in South America, and almost rivals Lake Ontario in size, having a length of 100 miles, a mean width of 35 miles, and a mean depth of 720 feet. The outflow from Lake Titicaca forms the river Desaguadero, which, after a course of 160 miles to the south, falls into the salt lake and swamps of Aullagas, scarcely one-third the size of Titicaca. The lake-system of the

* Called also the Marañon, and by the natives named the Parana-tinga, or Parana-uassu.

† Page 180.

river Andes, fresh water in the upper part and salt water in the lower part, reminds us of the river Jordan* system, and forms a *Basin of Continental Streams* between the eastern and western chains of the Andes, having an area of 200,000 sq. g. miles, about 1600 miles in length, and an average width of 120 miles—being a little more than one-sixth of the Continental River basin of Europasia.†

2°. From the little mountain lake just described there flows towards the north another stream, which forms the source of the *Rio Vilcanota*, which, under its successive names of Vilcamayo, Yucay, Urubamba, and Ucayali, forms the true parent stream of the giant Amazons, 3545 miles in length.

"A cork thrown into the centre of the lake might be carried into Titicaca, or into the Atlantic, depending probably on the direction of the wind."‡

This river joins the *Madeira*, one of the large southern branches of the Amazons, which joins it from the south about 150 miles below the point where the *Rio Negro* (communicating with the Orinoco by the Casiquiare) joins it from the north.

The enormous flat plains that form the upper Amazons' rain-basin are covered with forests, and called *Silvas;* and the surface covered by them is so vast, that when the earthlight is reflected from it to the dark surface of the moon, some astronomers have believed that they could distinguish in it the faint greenish tinge caused by the South American Silvas. "The whole country is not so much a vast network of rivers as an inland fresh-water sea filled with islands. It has been termed indeed the Medi-

* Page 170. † Page 175. ‡ *Peru*, &c. (Squier, 1877), p. 399.

terranean of South America; for not only is the main river broad, deep, and navigable by large vessels at every season of the year, but hundreds of tributaries, and numberless side branches connected with lakes scores of miles in circumference, add their quota to the great sum of navigable waters."*

The extracts quoted in the note from Mrs. Somerville and Mr. Bates will give the reader some faint idea of the wonders of the Amazonian Silvas.†

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* Bates, *Central America*, &c., p. 247.

† "According to Humboldt, the soil, enriched for ages by the spoils of the forest, consists of the richest mould. The heat is suffocating in the deep and dark recesses of these primeval woods, where not a breath of air penetrates, and where, after being drenched by the periodical rains, the damp is so excessive that a blue mist rises in the early morning among the huge stems of the trees, and envelops the entangled creepers stretching from bough to bough. A death-like stillness prevails from sunrise to sunset, then the thousands of nocturnal animals that inhabit these forests join in one loud discordant roar, not continuous, but in bursts. The beasts seem to be periodically and unanimously roused by some unknown impulse, till the forest rings in universal uproar. Profound silence prevails at midnight, which is broken at the dawn of morning by another general roar of wild chorus. Birds too have their fits of silence and song; after a pause they

> '. . . all burst forth in choral minstrelsy,
> As if some sudden gale had swept at once
> A hundred airy harps.'—*Coleridge.*

The whole forest often resounds when the animals, startled from their sleep, scream in terror at the noise made by bands of its inhabitants flying from some night-prowling foe. Their anxiety and terror before a thunder-storm is excessive, and all nature seems to partake in the dread. The tops of the lofty trees rustle ominously, though not a breath of air agitates them; a hollow whistling in the high regions of the atmosphere comes as a warning from the black floating vapour; midnight darkness envelops the ancient forests, which soon after groan and creak with the blast of the hurricane. The gloom is rendered still more hideous by the vivid lightning and the

The River Plate.—This vast river, the second largest in the world, is formed by the union of the *Parana* and the *Uruguay*, which unite to form the La Plata, which is rather an estuary of the sea than a river—being 62 miles across at Monte Video.

The country drained by the Plata has been justly called the Mesopotamia of South America. The Parana, and its tributary the Paraguay, are navigable for 1200 to 1500 miles from the sea; but the Uruguay is navigable for 300 miles only.

The following brief account of the Parana, by an eye-witness, will give some idea of this great river:*—

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stunning crash of thunder. Even fishes are affected with the general consternation; for in a few minutes the Amazon rages in waves like a stormy sea.

"The accounts of travellers dwell frequently on the stillness and sombre awfulness of these primeval woodlands, and not without reason, for such impressions are fully confirmed by a lengthened abode in these regions. The far too rare voice of the feathered tribes is of a melancholy and mysterious nature, calculated rather to quicken the sense of loneliness than to gladden and animate the wayfarer to fresh efforts. At times there echoes in the midst of the deep silence a sudden shriek of anguish or alarm, for a moment arresting the beat of the heart. It is the cry of some luckless herbivorous creature that has unexpectedly fallen a prey to some member of the feline order, or become entangled in the coils of a boa-constrictor. Morning and evening the numerous apes of the "howler" tribe set up a horrible din, increasing tenfold the inhospitable character of the forest. And often the dead stillness of noon is broken by a sudden crash dying away in the distance, and caused by some huge branch, or even by a whole tree, falling to the ground. Nor is there any lack of strange noises, baffling all attempts at explanation. At times a sound is heard resembling that of an iron bar beaten against some hard or hollow block, at others like a piercing shriek rending the air. But neither the dull sound nor the shrill cry is repeated, and the return of perfect stillness enhances the harrowing effect produced by its momentary interruption."

* Edwin Clark, *Visit to South America*, p. 275, *et seq.*

"It is impossible to convey any adequate idea of the magnitude of the enormous rivers which empty themselves into the Plate by any comparison with our own rivers. The Parana is the second largest river in the world. For a distance of 600 miles the two banks are rarely simultaneously visible. The steamer plods her way, day after day, against the current, among endless groups of large islands or through extensive lake-like vistas, sometimes intercepted by shallows, which are avoided by crossing or recrossing from island to island. The barranca, or cliff, which defines the limits of the old river bed, is occasionally seen, and often forms a prominent object many miles inland; but the actual banks undergo perpetual transformation, as the river, in its continual change of *régime*, ploughs away the alluvium where the stream is strongest, and deposits it in the form of new islands, or rush-grown flats, where eddies or quiet waters allow of its subsidence. As the lands that are so denuded are usually covered with timber, the banks are lined with rafts of timber, or with falling trees whose roots are bared by the current. Cranes, storks, and other large birds sit motionless on these piles of ruin, or fly lazily away as the steamer approaches them; while the carpinchos and other animals flounder about beneath them; and higher up the river the alligators lie basking on every sloping beach.

"In going to Asuncion we leave the Parana at Corrientes, 686 miles from the Plate. Even at this point it drains a mountainous region exceeding 500,000 square miles in area, but its sources are nearly as mysterious as those of the Nile. All navigation is stopped at the great falls of Guaiva, 1136 miles from the Plate. Azara, who visited these falls in 1788, describes the river as 14,000 feet wide, suddenly reduced at the cataract to 200 feet. Thus confined, its waters break with indescribable fury; they drop fifty-six feet over a plane of granite, at an inclination of about fifty degrees; the clouds of spray form columns of vapour, lit up with rainbows, which are visible for many leagues. A continuous rain is produced by the condensation, and the roar is heard at twenty miles distance. The district is inhabited by a low race of Indians. Beyond this point all is unexplored; the Rio Pardo is a tributary at 1400 miles, and the Rio Grande at 1820 miles from the Plate, and at this point it first takes the name of the Parana. For technical details of this extraordinary river, see *Hydraulics of Great Rivers*, by J. J. Revy, 1874.

"The tributaries of the Parana are gigantic rivers. The Salado, the Vermejo, the Paraguay, and Pelcomayo are all nearly a thousand miles in length, and run through vast districts occupied by Indian tribes, totally unexplored.

"The field which these prolific regions open for the ambitious traveller are unbounded; and as the steamers which navigate the main rivers are fitted up with great comfort, and even luxury, and as the political conflicts which have so long rendered them inaccessible are now at an end, there is no longer any difficulty in exploring a country which is unrivalled for its beauty and fertility, and which is almost entirely unknown. The journey from Buenos Ayres to Asuncion is performed by the steamers in about seven days. The latitude of Buenos Ayres is 34° 36′, and of Asuncion 25° 20′, but the longitude is nearly the same, so that the journey is due north, and is a continuous approach to the tropics.

"The distance by the river is approximately as follows:—

	Leagues.
Buenos Ayres to Rosario, ...	75
Rosario to Parana, ...	40
Parana to La Paz, ...	40
La Paz to Esquina, ...	22
Esquina to Goyaz, ...	30
Goyaz to Bella Vista, ...	20
Bella Vista to Corrientes	30
Corrientes to Asuncion on the Paraguay,	100
	357, or 1071 miles.

"In the journey to Asuncion, the Parana is ascended as far as Corrientes; the remaining 300 miles are on its noble tributary, the Paraguay.

"The increasing temperature of the river water is a fair index of the change of climate. It increases at the rate of a little more than 1° F. for every degree of latitude, the temperature of the water in August being 62° at Rosario, and 70° at the entrance of the Paraguay. The waters of the Paraguay are much warmer, being 79° off Asuncion.

"The height of the river above the sea is 250 feet at Asuncion, 200 feet at Corrientes, 100 feet at La Paz, and 60 feet at Rosario. The fall is, therefore, over 2½ inches per mile for the whole distance, or 2 inches per mile on the Parana. Its tributary the Salado, in the Gran Chaco, falls with perfect uniformity five inches per mile for 700 miles, while the country itself, in a straight line, falls twelve inches per mile. The uniformly increasing gradient with which the pampas everywhere rise, from the river valley up to the Andes, has been already alluded to.

Cordova and Tumman are 1300 feet and 1200 feet above the sea, while Mendoza and San Juan are 2400 and 2200 feet. The scale over which this simple and uniform *régime* is maintained is the most striking characteristic. This is prominently forced upon us as we ascend this mighty river: no evident diminution in its width or volume can be detected when travelling night and day in a rapid steamer for three or four successive days. We appear to sail from lake to lake amidst a labyrinth of luxurious islands, occasionally threading some narrow channel, to enter again some magnificent reach, shut in by dense and forest-like vegetation, which we soon discover to be only another branch of the great network of streams and rivers and lakes of which the great system is composed, but the actual banks are rarely, if ever, simultaneously visible. The barranca, or old river boundary, occasionally towers up in the distance in the form of tosca cliffs: among the trees on the Entre Rios shore, and at Parana, cliffs of tertiary limestone rise out of the river. They contain beds of shells, and large deposits of a gigantic fossil oyster, the *Ostrea Patagonica*. This shell conglomerate is largely burnt for lime. The town is built on the high ground, communicating by means of a tramway with the iron jetty on the river. This little geological feature is quite exceptional, the river, as a rule, maintaining its shifting channels through vast deposits of alluvium almost from the tropics to the Plate. The river here is washing away its eastern margin. At Rosario its bed was travelling west. Very few vessels passed us; and though a few large birds were perched on fallen trees, or among the rush-grown swamps, the total absence of any sign of human life gave an imposing stillness and vastness to the scene; but the gradual approach to the tropics, which slightly changed the vegetation from day to day, effectually prevented monotony. A few palms appeared at Santa Fe. The yucca grew on the limestone cliffs, and numerous brilliant creepers towered among the trees, which, with the foliage, gave an English park-like aspect to some of the glades."

The Mississippi-Missouri River System.—This magnificent river system has been more carefully surveyed and examined than that of any great river, and I shall here give a brief account of it, regarded as our standard of great rivers.

Humphreys and Abbot* published, in 1861, their well-known Report, from which the following facts are taken: the Mississippi is 2500 ft. wide at New Orleans, 4000 ft. wide at the junction of the Ohio, and 3500 ft. wide at the junction of the Missouri.

From near the mouth of the river, at Balize, a steamboat may ascend for 2000 miles with scarcely any perceptible difference in the width of the river. The tributaries of this great river, such as the Red River, the Arkansas, the Missouri, the Ohio, and others, would be regarded elsewhere as of the first importance, and, taken together, are navigable for a distance many times exceeding that of the main stream.

The rain-basin of the whole river system is 982,400 sq. geo. miles. The watershed of this vast basin varies greatly in different parts: on the west, from the 38th to the 48th degree of N. Lat., the Missouri drains the lofty ridges of the Rocky Mountains, averaging from 8000 ft. to 10,000 ft. in altitude; while on the north the watershed

* "Report of the Survey of the Mississippi" (1861).

which separates the Mississippi basin from that of the St. Lawrence runs across the central plain of North America between the 46th and 50th parallels, and is nowhere more than 1500 ft. to 1600 ft. above the sea level.*

Fig. 30 is an Orographical Map of North America, showing the mountain chain of the Rocky Mountains on the west coast; and also showing that the lower basin of the Mississippi-Missouri is fed by the north-east Trade-wind vapour, carried from the Atlantic, and condensed by the Mexican and Rocky Mountains' chains.

The mean annual water-discharge of the various branches of the Mississippi, determined from observations extending over 33 years, are thus stated by Humphreys and Abbot:—

	Cubic feet.	Cubic miles.
1. Upper Mississippi, .	3,300,000,000,000	
2. Missouri (*a*), ...	3,780,000,000,000	
3. Ohio (*b*), ...	5,000,000,000,000	
4. Arkansas and White River, ...	2,000,000,000,000	
5. Red River, ...	1,800,000,000,000	
6. Mississippi - Missouri system † (excluding Red River), measured at *Natchez*, . . .	19,400,000,000,000	‡131·80

* The city of Chicago is supplied with fresh water by a tunnel from Lake Michigan, in the St. Lawrence basin; and the drainage of the city is discharged through a branch of the Mississippi into the Gulf of Mexico.

† This water-discharge ranges from wet to dry years from 27,000,000,000,000 cubic feet to 11,000,000,000,000 cubic feet; or, from 183·43 cubic miles to 74·73 cubic miles per annum.

‡ It is worthy of remark, that the Gulf Stream (p. 136) would deliver this amount of water in 3 h. 29 m., instead of requiring a whole year.

(*a*). This discharge is only *one-seventh* part of the rainfall.

(*b*). This discharge is *one-fourth* part of the rainfall.

In Fig. 31 is shown the delta of the Mississippi-Missouri, extending, with a snake-like head, far out into the Gulf of Mexico. It presents a striking contrast, in this respect, to the deltas of the Ganges-Brahmapûtra and Nile, shown in Fig. 25 and Fig. 29.


NORTH AMERICA
HUDSON'S BAY
NORTH PACIFIC OCEAN
NORTH ATLANTIC OCEAN
GULF OF MEXICO
80
180
160
140
120
100
80
60
40
20
80
60
40
20
0
120
100
80

Fig. 30.


DELTA OF THE MISSISSIPI
LAKE PONTCHARTRAIN
NEW ORLEANS
MISSISSIPI RIVER

Fig. 31.

Note A.

The Annual Water-discharge of the River Plate.

Mr. Bateman's estimate of the December low-water discharge of the Rio de la Plata is given in the following extract from a Report drawn up by him for the Government of Buenos Ayres, 9th January, 1871 :—

"The Rio de la Plata, formed by the junction of the rivers Parana and Uruguay, is the widest fresh-water river in the world. Assuming it to terminate in a line drawn from Monte Video on the north to Piedras point on the south (though it is generally described as extending much further), it is 60 miles in width at its mouth. At 60 miles further up it is still 40 miles wide. At Colonia, the narrowest part, and 80 miles from the sea, it is 23 miles wide. At Buenos Ayres, 100 miles from the sea, 30 miles wide; and just below the junction of the various mouths of the Parana with the Uruguay, 120 miles from the sea, it is 26 miles wide. The volume of fresh water it conveys to the sea is probably exceeded only by the Amazon.

"The total area of the basin has been estimated at 1,250,000 square miles*. The Parana, its chief feeder, takes its rise in Brazil, within the tropics, and is swollen by the tropical rains of that region. At about 27° S. latitude it is joined by its most important tributary, the Paraguay. Some of the branches of this river extend to within 12° of the equator, and are also fed by tropical

* This is equivalent to 968,000 sq. geo. miles.

rains; while others issue from the Cordilleros de los Andes, and are periodically swollen by the melting of the snows which rest on the high points of that range of mountains. For 700 or 800 miles, these mountains shed the waters which fall on their eastern slopes to the Paraguay or the Parana, and some smaller streams from the lower lands of the province of Buenos Ayres enter the Plate near the *embouchure* of the Parana.

"The Uruguay, the other great tributary of the Plate, descends from the central part of South America, draining a vast area, and swollen periodically by tropical rains.

"The detritus, or suspended matter, brought down by these streams, has formed the delta of the Parana, the islands which are clustered about its various mouths, and the shoals of the River Plate.

"It was considered a matter of great importance, as bearing directly upon the question of the practicability of improving the harbour accommodation of Buenos Ayres, to ascertain the volume of these streams, and the quantity of matter which they carried in suspension.

"For this purpose careful measurements have been made during the month of December, 1870.

"The Parana was in its lowest state—a continuous drought of six or seven months having diminished the ordinary sources of supply, and the periodical rise resulting from the melting of the snows of the Andes not having yet commenced. This river is stated to be generally lowest in the month of December, from which time it begins to rise: it is said to attain its greatest height in March, and to continue at nearly its maximum level, with little variation, for several months. At Las Hermanas, between Obligado and San Nicolas, the flood level was distinctly visible at 16 feet 4 inches above the level of the water at the time of my visit, 17th of December, 1870. The river was stated to have remained at this flood level for eight months. Measurements of the river were made at Obligado, and of the various branches lower down, including the Ibucuy, so as to ascertain the actual quantity of water which was flowing into the Plate. It amounted to 520,000 cubic feet of water per second, and this may be considered as the minimum volume of the river. I hope to get further measurements when the river is in a state of flood.

"The Uruguay we have not yet had an opportunity of measuring; but from some particulars of depth and velocity, given by Captain Page in his survey of the river for the United States Government in the spring of 1855, and by computations from the chart prepared for the British Admiralty by Captain Sulivan and others, I venture to calculate that it may approximately be rated at about 150,000 cubic feet per second in its lowest state, making the total minimum volume of water poured into the River Plate, if the condition of low water occur in both rivers at the same time, about 670,000 cubic feet per second—a quantity equal to the mean volume of thirty-three years passing down the Mississippi."

Mr. J. J. Revy, an Austrian engineer, was employed by Mr. Bateman as his assistant in the survey of the River Plate; and he subsequently published (without any authority from Mr. Bateman) a work* containing results deduced from the observations made under Mr. Bateman's directions, without any suitable acknowledgment of Mr. Bateman's rights of ownership.

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* *Hydraulics of Great Rivers.* London and New York (1874).

If Mr. Revy's observations can be relied on, they lead to conclusions of considerable consequence—the most important of which is, that the mean *velocity* of the *water-discharge at any point of the cross section of a large river is simply proportional to the depth of the river at that point.*

This proposition may be illustrated by the following observations made on the Parana and on the Uruguay:—

I.—*Cross Section of the Parana, made near Rosario, on the 25th January,* 1871.

Let v = the mean velocity from surface to bottom at any point, expressed in feet per minute.

d = the depth at any point expressed in feet.

The mean velocities and depths were taken at nine stations across the river, with the following results:—

Station.	v	d	$\frac{v}{d}$
1°	108·4 ft. per minute.	24·4 feet.	4·44
2	253·8 ,,	68·5 ,,	3·71
3	255·3 ,,	58·5 ,,	4·37
4	241·0 ,,	53·7 ,,	4·49
5	215·3 ,,	49·0 ,,	4·39
6	195·0 ,,	42·0 ,,	4·64
7	172·2 ,,	40·0 ,,	4·33
8	129·2 ,,	33·0 ,,	3·92
9	89·5 ,,	20·0 ,,	4·44
Mean, ...			4·3033

II.—*Cross Section of the Uruguay, made near Salto, on the 3rd February,* 1871 :—

Station.	v	d	$\frac{v}{d}$
1°	79·6 ft. per minute.	13·1 feet.	7·45
2	234·2 ,,	22·0 ,,	10·64
3	261·4 ,,	25·0 ,,	10·45
4	281·7 ,,	29·0 ,,	9·71
5	301·3 ,,	29·8 ,,	10·11
6	329·8 ,,	33·0 ,,	9·99
7	317·5 ,,	30·0 ,,	10·25
8	319·5 ,,	31·0 ,,	10·03
9	333·1 ,,	30·0 ,,	11·10
Mean, ...			9·970

If we assume that the mean velocity of the discharge at any point is proportional to the depth at that point, we may calculate the total water-discharge of the river as follows:—

Let y denote the depth of the river, and x the corresponding distance from the bank of the river; then we shall have, to express the curve of the river-bed,

$$y = \phi(x);$$

also, we have

$$v = ky;$$

where k is the coefficient expressed in the last column of the preceding Tables.

The cross-section of any elementary slice of the river is ydx, and the corresponding discharge is

$$v \times ydx,$$

or

$$ky^2dx.$$

Hence,

$$Q = k\int y \times ydx \qquad (1)$$

where Q is the total water-discharge; or, finally,

$$Q = 2k \times y_1 \times A; \qquad (2)$$

where y_1 is the depth of the centre of gravity of the cross section of the river, and A is the area of the cross section. Both these quantities may be found, without calculation, by experiments made upon a zinc templet, drawn to scale, representing the cross section of the river.

It is well known that $A \times y_1$ is the volume of water, whose weight denotes the *hydrostatic pressure* upon the river section, regarded as a boundary wall; hence we have the proposition—

The quantity of water discharged by a river in a given time is proportional to the hydrostatic pressure on the river section, multiplied by a coefficient which varies with the river basin.

We may now apply the foregoing to calculate the discharge of the Parana at Rosario, on the 25th January, 1871.

The cross section of the river may be divided into six parts, according to the varying slope of the bottom, as follows:—

Station.	Depth.	Horizontal Distance from last Station.
0°	0·00 feet.	0 feet.
1	12·33 ,,	860 ,,
2	24·42 ,,	97 ,,
3	73·10 ,,	110 ,,
4	59·10 ,,	750 ,,
5	37·75 ,,	1980 ,,
6	0·00 ,,	960 ,,

The first and last of these sections are triangles, and the others are trapezia. The areas and hydrostatic pressures of the several sections are given in the following Table:—

Section.	Area.	Product, Ay_1.
0° to 1°	5303 sq. ft.	21,790 cub. ft.
1 ,, 2	1782 ,,	16,994 ,,
2 ,, 3	5122 ,,	141,626 ,,
3 ,, 4	69575 ,,	1,269,760 ,,
4 ,, 5	95880 ,,	2,357,550 ,,
5 ,, 6	18120 ,,	228,015 ,,
	195,782 ,,	4,035,735 ,,

In order to find the discharge, we must multiply the total hydrostatic pressure by $2k$ from equation (2), and divide by 60, to reduce to cubic feet per second. This gives us

$$Q = \frac{4,035,735 \times 8 \cdot 6067}{60}$$

$$= 578,910 \text{ cubic feet per second,}$$

which agrees with Mr. Bateman's minimum result for December, viz., 520,000 cubic feet per second.

The water-discharge of the Uruguay on the 3rd February, 1871, may be thus found:—

Station.	Depth.	Horizontal Distance from last Station.
0°	0·00 feet.	0 feet.
1	18·25 ,,	220 ,,
2	34·50 ,,	1560 ,,
3	24·33 ,,	710 ,,
4	31·00 ,,	160 ,,
5	0·00 ,,	90 ,,

From this we calculate the following Table of hydrostatic pressures:—

Station.	Hydrostatic Pressure, Ay_1.
0° to 1°	12,215 cubic feet.
1 ,, 2	559,250 ,,
2 ,, 3	310,790 ,,
3 ,, 4	61,627 ,,
4 ,, 5	14,415 ,,
	958,297 ,,

This result, multiplied by twice the Uruguay basin coefficient for 3rd February, 1871, and divided by 60, gives us

$$Q = \frac{958{,}297 \times 19{\cdot}940}{60}$$

$$= 318{,}470 \text{ cubic feet per second.}$$

Note B.

New Method of Calculating the Annual Water-discharge of the Nile.

I propose, in this note, to calculate the annual water-discharge of the Nile from the following data:—

1°. *The actual measured maximum and minimum discharge.*

2°. *The actual measurements of depth taken from day to day on the Nilometer.*

Various hydraulic theories lead up to the idea that, in large rivers, the water-discharge varies simply as the cube of the linear dimensions of the river. This may be readily deduced from the hydraulic theory of the preceding note; where we have

$$Q = 2k \times y_1 \times A. \qquad (2)$$

If k be a *constant* depending on the configuration of the river basin only, and if the river section remain similar to itself at the place of observation, then A will vary as the square of the linear dimension, and y_1 will vary as the simple linear dimension; and therefore

$$Q \propto h^3, \qquad (3)$$

where h is a linear dimension of the river section.*

* This quantity h may be regarded as the *Hydraulic Mean Depth* of writers on Hydraulics.

The French expedition to Egypt, in 1799–1801, obtained the following results:—

		Cubic Meters per Second.
1°.	Maximum discharge in September,	10247
	Minimum discharge in June, . .	678

2°. The average of the two years' measurements on the Nilometer at Cairo give the following depths, measured from an arbitrary zero, to which I have added an unknown quantity, x, to be found from theory and observation:—

The Nilometer at Cairo, 1799–1801.

1. September,	. 152 + x.	7. March, . .	48 + x.
2. October, .	. 127 + x.	8. April,. . .	39 + x.
3. November,	. 105 + x.	9. May, . . .	25 + x.
4. December,	. 86 + x.	10. June, . . .	24 + x.
5. January, .	. 72 + x.	11. July, . . .	40 + x.
6. February,	. 58 + x.	12. August, . .	111 + x.

Let x be the unknown line, to be added to the depths measured from the arbitrary zero, to convert them into h (the *hydraulic mean depth*, or standard linear dimension of the river bed).

If equation (3) be true, we have from the foregoing data—

$$\left(\frac{152 + x}{24 + x}\right)^3 = \frac{10247}{678}; \qquad (4)$$

from which we find

$$x = 63, \text{ q.p.}$$

Substituting for x its value, we obtain the following Table:—

Linear Dimension of Nile, at Cairo, in 1799–1801.

	h.		h.
1. September, . .	215	7. March, . . .	111
2. October, . . .	190	8. April, ...	102
3. November, . .	168	9. May, ...	88
4. December, . . .	149	10. June, ...	87
5. January, . . .	135	11. July, ...	103
6. February, . . .	121	12. August, . . .	174

From (3), and the preceding Table, we find

$$Q = 678 \left(\frac{h}{87}\right)^3. \qquad (5)$$

Calculating by this formula, I find

Water-discharge of Nile, at Cairo, in 1799–1801, *expressed in Cubic Meters per Second.*

	Q.		Q.
1. September, . .	10,274	7. March, . . .	1,408
2. October, . . .	7,062	8. April, . . .	1,093
3. November, . .	4,882	9. May, . . .	702
4. December, . .	3,406	10. June, . . .	678
5. January, . .	2,533	11. July, . . .	1,125
6. February, . .	1,824	12. August, . .	5,424

$$\text{Total mean discharge} = \frac{40{,}411}{12}$$

= 3,367 cubic meters per second

= 4,404·108 cubic yards per second

= 118,900 cubic feet per second

= **25·49** cubic miles per annum.

LECTURE VI.*

ON THE GEOGRAPHICAL DISTRIBUTION OF ANIMALS AND PLANTS.

LADIES AND GENTLEMEN,

The subject of our concluding Lecture, viz., *The Geographical Distribution of Animals and Plants*, is one of extreme interest, and great difficulty; and I can only hope to give you an imperfect outline of a few important facts, and of the attempts that have been made to explain those facts.

Let us commence by a few instances, to illustrate my meaning.

Has it ever occurred to you to ask why the Old World produces *Coffee*, while the New World produces *Cinchona* and *Ipecacuanha* from plants of the same Natural Family of *Cinchoneæ*?

How does it happen that the Natural Family of *Solanaceæ* gives us in the New World the *Potato* and *Tobacco*, which did not originate from that Family in the Old World?

Why are *Lions*, *Tigers*, and *Leopards* produced by the Old World, while *Pumas* and *Jaguars* are produced by the New World?

---

* This Lecture was delivered on the 8th April, 1876.

Why do we associate the *Date Palm* with Syria, the *Cobra* with India, and the *Giraffe* and *Antelopes* with Africa?

The name of Brazil recalls to our minds its *Sloths* and *Toucans;* and the thought of Australia brings up the recollection of its *Kangaroos* and *Gum Trees.*

Geographical Distribution of the King Crabs.—The King Crabs are a very peculiar family of Crustaceans, the few living forms of which belong to the same genus *Limulus.* Of this genus there are four species recognized: one, *L. Polyphemus*, is found on the coasts of Nova Scotia; and another, *L. Moluccanus*, is found in the Moluccas, on the coasts of the islands of Sunda and Molucca: the two remaining species are found—one on the coasts of Japan, and the other in the East Indies. All four species are closely allied, and the Moluccan king crab is so nearly related to the Nova Scotian king crab, that some naturalists consider they may be the same.

The question now arises, whether North America and Asia produced, independently, two remarkable, almost identical, types of Crustacean; or whether they may not both be the lineal descendants of older and extinct king crabs, produced neither in Asia nor in North America, but in some older Continent, from which their descendants may have migrated, at different times, into North America, Japan, and the East Indian Archipelago.

In support of the latter hypothesis, it may be mentioned that the remarkable natural family (*Xiphosura*), to which the king crabs belong, is very ancient, having representatives in the period of the Coal Measures (*Bellinurus*), and, possibly, allies in pre-Carboniferous times (*Eurypterus* and *Pterygotus*).

Geographical Distribution of the Ostrich Family.—The distribution of the Ostrich Family and its allies affords us an excellent illustration of the problems offered for solution by the subject of our present Lecture.

The ostriches and their allies form families grouped under a sub-class (*Ratitæ*) of birds, which differ so widely from other birds that they are properly placed in a sub-class by themselves.

The six families of the *Ratitæ* are given here, with their respective geographical distributions :—

I. *Struthionidæ* = *Ostriches.*

Desert regions of North, East, and South Africa; also, Arabia and Syria. (Two species.)

II. *Rheidæ* = *South American Ostriches.*

Temperate South America, from Patagonia to the confines of Brazil. (Three species.)

III. *Casuarinidæ.*

(*a*). *Casuarius* = *Cassowaries.*

East Indian Archipelago and North Australia.* (Nine species.)

(*b*). *Dromæus* = *Emus.*

Mainland of Australia. (Two species.)

IV. *Apterygidæ* = *Kiwis.*

New Zealand.

---

* There is only one species in the mainland of Australia: Papua is the proper centre of the Cassowaries.

V. *Dinornidæ* = *Moas.*

(*a*). *Dinornis.* (Five species.)

(*b*). *Meionornis.* (Two species.)

Recently extinct in New Zealand, mostly large, and some gigantic.

VI. *Palapterygidæ.*

(*a*). *Palapteryx.* (Two species.)

(*b*). *Euryapteryx.* (Two species.)

Recently extinct in New Zealand, mostly large, and some gigantic.

VII. *Æpyornidæ.*

Recently extinct in Madagascar, of gigantic size; its fossil eggs are estimated at twenty-four pounds weight each, or eight times the bulk of those of the Ostrich, and are supposed to be the Roc's Egg of the Arabian fables.

The following remarks may be made upon the foregoing distribution of these very remarkable birds:—

1. They belong to the Southern Hemisphere.

2. The two genera, which are most closely allied,* viz.,

* I have shown (*Animal Mechanics*, pp. 428–30), that the close relationship between the *Ostrich* and the *Rhea*, and between the *Cassowary* and *Emu*, may be traced even in the minute details of the muscular structure of their dwarfed wings. We are not, therefore, surprised to find the *Emu* and *Cassowary* dwelling in the same zoological region; but it is a matter difficult of explanation, why the *Ostrich* and *Rhea* are in zoological regions so remote from each other as Africa and South America.

the *Ostrich* and the *Rhea*, are confined to two continents, Africa and South America, widely separated by a remarkably deep sea.*.

3. The occurrence of gigantic forms of extinct *Ratitæ* in New Zealand and Madagascar renders it probable that these islands were formerly portions of large continents now submerged.†

It should be added that a few fossil remains of *Ratitæ*, perhaps allied to the *Ostrich*, *Dinornis*, and to wading birds, have been found in the Lower Eocene of England and France.

The remarkable zoological position of the *Ratitæ* renders everything relating to them of great interest.

Their position is thus shown: there are about 8,000 known species of birds, which are subdivided into three sub-classes, viz. :—

Sub-class I.—SAURURÆ.

This includes one bird only—the extinct *Archæopteryx*, from the Oolitic lithographic limestone of Solenhofen—characterized by the possession of a tail longer than the body, of about twenty caudal vertebræ, and clothed with lateral feathers.

The Archæopteryx is a connecting link between the true Birds and the Ornithoscelidan reptiles, which include *Iguanodon*, *Megalosaurus*, and *Compsognathus*.

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* *Vide* Fig. 7, p. 47.

† All our knowledge points to the influence of the size of continents on the size of the animals produced by them. Buffon, indeed, accounts by this influence for the inferiority of the American animals, as compared with those of Europasia and Africa.

Sub-class II.—RATITÆ.

Just described.

Sub-class III.—CARINATÆ.

Contains all other birds.

Geographical Distribution of the Non-placental Mammals.—The non-placental Mammals contain two great sub-divisions, viz., the *Marsupials* and the *Monotremes*, and their geographical distribution is very remarkable. The *Monotremes* contain two genera—

1. *Ornithorhynchus*, *Duck-bill.*
2. *Echidna*, . . . *Australian Hedgehog.*

These genera are restricted to East and South Australia and Tasmania, with the exception of *Echidna*, a species of which has been recently found in Papua.

The Marsupials are sub-divided into the following seven families:—

1. *Didelphyidæ*, . . *Opossums.*
2. *Dasyuridæ*, . . *Native Cats.*
3. *Myrmecobiidæ*, . *Native Ant-eaters.*
4. *Peramelidæ*, . . *Bandicoots.*
5. *Macropodidæ*, . *Kangaroos.*
6. *Phalangistidæ*, . *Phalangers.*
7. *Phascolomyidæ*, . *Wombats.*

The remarkable fact in the distribution of these seven families is, that the first of them, *Opossums*, is not found in Australia at all, but occurs abundantly in South and Central America, and one species occurs in North America.

The remaining six families, like the Monotremes, are confined to Australia and its islands.

These facts seem to point to two distinct centres of distribution for the non-placental Mammals now living.

Seven species of Opossum have been found, fossil, in caves of Brazil, while the living species only has been found in the North American Post-Pliocene deposits. In Europe, however, many species of small Opossums, classed in a genus *Peratherium*, have been found in Tertiary deposits, ranging from the Upper Miocene as far back as the Upper Eocene.

Mr. Wallace is of opinion that it is thus proved that the American Marsupials have nothing to do with those of Australia, but were derived from Europe, where their ancestors lived during a long series of ages.*

With regard to the ancestors of the Australian non-placental Mammals, the following facts are known:—

(*a*). Extinct species of *Native Cats* have been found in the Post-Pliocene deposits of Australia.

(*b*). Many species of fossil *Kangaroos* have been found in the Post-Pliocene beds of Australia, including the gigantic *Diprotodon*, nearly as large as a camel, and the *Nototherium*, nearly as large as a rhinoceros.

(*c*). A *Wombat* as large as a tapir has been found in the Australian Pliocene deposits.

(*d*). There is a large extinct Australian Marsupial, called *Thylacoleo*, as large as a zebra, which Mr. Gerard Krefft believes to be a *Phalanger*.

(*e*). Remains of a very large fossil *Echidna* were found (1868) at Darling Downs, in Australia.

* *Geographical Distribution of Animals*, vol. ii. p. 249.

These facts point to a former existenee of Australia as a portion of a much larger Continent; and, at the same time, the remarkable development of a great variety of species and types, especially of the *Phalangers*, bears testimony to the long lapse of time necessary for the production of Australian Fauna.

In considering the probable origin of the non-placental Fauna of Australia and its islands, it must be borne in mind that a Marsupial Fauna existed in Europe and North America in Mesozoic times.

The following is a brief outline of what is known of this, the earliest development of Mammals on our planet.

In the Upper Trias of Germany and England, mammalian teeth of a small Marsupial, *Microlestes*, have been found, which show a relationship to *Myrmecobius*, the living Australian Ant-eater, and also to *Plagiaulax*, a Marsupial fossil of the English Purbeck beds (Upper Oolite).

In beds of the same age, as nearly as can be ascertained, two lower jaws were found by Prof. Emmons, in North Carolina, of a Marsupial, called by him *Dromatherium*, which is also related to the *Myrmecobius* of Australia.

In the Lower Oolite of England (Stonesfield Slate), lower jaw bones of three Marsupials (probably insectivorous), named *Amphitherium*, *Phascolotherium*,* and *Stereognathus*, have been long known; and one of them, preserved in the Ashmolean Museum at Oxford, was seen by Cuvier, and declared by him to be Marsupial,

* This animal agrees completely, in its dentition, with the living Opossums, *Didelphys*.

from a now well-known configuration of a process of the jaw, intended for the attachment of the internal pterygoid muscles.

The Middle Purbeck beds of the South of England (Upper Oolite) have afforded relics (all lower jaws) of fourteen species of Marsupials, belonging to eight genera; most of them insectivorous, but one, *Plagiaulax*, related to the Kangaroo Rat, and another, *Galastes*, probably carnivorous.

Quite recently, Professor O. C. Marsh has found, in the Jurassic beds of the Rocky Mountains, in North America, five lower jaws of small insectivorous Marsupials, of which three belong to the genus *Dryolestes*, closely related to the Opossum, *Didelphys;* and the other two in many respects show affinities with *Stylodon* and *Triconodon*, described by Professor Owen, from the Purbeck beds of England.

This discovery would seem to render it probable that the small Mesozoic Marsupials of the Jurassic period were the ancestors of the American opossums; but it is extremely doubtful if the Marsupials of the Mesozoic strata of Europe and North America were the ancestors of the Australian Marsupials; and it is much more likely that the varied and often gigantic Marsupial Fauna of the Australian region was developed, independently, in the Southern Hemisphere, at a time when Australia had land connexions with the Antarctic Continent, and when that continent, like the Arctic Regions, enjoyed a moderately warm climate.

Geographical Distribution of the Edentates. — The *Edentates* are among the lowest forms of placental Mammals, and their geographical distribution leads to conclusions similar to those suggested by the distribution of the struthious birds, as to the relations in former times between South America and Africa.

They are divided into the following five Families :—

1. *Bradypodidæ*, . *Sloths.*
2. *Dasypodidæ*, . . *Armadilloes.*
3. *Myrmecophagidæ*, *South American Ant-eaters.*
4. *Manidæ*, . . . *Scaly Ant-eaters.*
5. *Orycteropodidæ*, . *Aard-vark*, or *Cape Ant-eaters.*

Of these five families, the first three are found only in South America; the fourth (*Scaly Ant-eaters*)* do not occur in South America, but are found in Africa and in Southern Asia and South China, as far as Amoy, Hainan, and Formosa; and the fifth family (*Aard-vark*, or *Cape Ant-eaters*) is found only in South and West Africa.

If we examine the fossil ancestors of this remarkable order of animals, we shall see strong reasons for attributing to them a Southern origin, from a common Antarctic Continent, such as was, probably, the original home of the *Ratitæ* among birds.

1. Many extinct fossil *Sloths* are found in the caves of Brazil; and in the Pliocene deposits of La Plata and Patagonia; and gigantic terrestrial Sloths† are

* The *Scaly Ant-eaters* are closely related to the *South American Ant-eaters*, even in minute details of muscular structure (such as the arrangements for retracting the long tongue), just as the *Rhea* is closely related to the *Ostrich*.

† Many of these gigantic Sloths migrated into North America, as far as Pennsylvania, the St. Lawrence Lakes, and Oregon.

found, viz., *Megatheridæ*, *Megalonychidæ*, *Mylonidæ*, and *Scelidotheridæ*.*

2. Many extinct fossil *Armadilloes* are found in the caves and Pliocene deposits of South America, including the gigantic *Glyptodontidæ*, *Schistopleuridæ*, and *Chlamydotheridæ*, some of which were as large as the tapir, rhinoceros, or even the elephant.

3. Of the Ant-eaters of South America, only one fossil form has been found in that country, viz., *Glossotherium*.

4. No fossil forms of the *Scaly Ant-eaters* or *Pangolins* have been yet found; possibly they may await us in Africa.

5. Of extinct *Aard-varks*, or *Cape Ant-eaters*, it is curious that fossil remains have been found in Europe: one, a huge animal, *Ancylotherium*, in the Miocene deposits of Greece.

The foregoing evidence all points to a development of Edentates in the Antarctic Continent (then enjoying a mild climate), and communicating easily with South America, *viâ* Louis Philippe Land, South Shetlands, and Cape Horn (in shallow water); and with South Africa, by a more circuitous route (all in shallow water), viâ Enderby Land, Kerguelen's Land,† the Crozet Islands, Prince Edward's Island, and the Cape of Good Hope.

The Edentates of South America, unquestionably, spread into North America, and flourished long in both Continents; while the Edentates of Africa spread into Asia and Europe, and were, finally, nearly extinguished,

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* These have some relationships to the *Cape Ant-eaters*.

† Fossil trees, possibly of Miocene age, exogenous, and of large size, have been found in Kerguelen's Land.

in Miocene times, by the invasion of Africa, from the north, by the multitude of highly organized Ungulates and Carnivores which constitute so remarkable a feature in the history of that continent.

The Geographical Distribution of the Humming Birds.—One of the most remarkable cases of distribution of animals is to be found in the Humming Birds, which are confined exclusively to the New World, where they range from Sitka, in the north, to Cape Horn, in the south. They are extremely abundant in the forests of the Andes, from Chili to Mexico, and reach the limits of perpetual snow.

I mention them here, as an example of the natural product of a continent, nowhere repeated.

The Geographical Distribution of the Monkeys and Apes furnishes an excellent illustration of the limitation of special families and sub-orders to special continents.

Excluding Man, the whole order is divided into three sub-orders, viz. :—

1. *Catarrhini*, . *The Old World Monkeys and Apes.*
2. *Platyrrhini*, . *The New World Monkeys.*
3. *Arctopitheci*, . *The Marmosets.*

The first of these sub-orders is found in the tropical and sub-tropical districts of Africa and Asia, some few extending into Europe and the tropical islands of Australia.

The second and third of the sub-orders are confined to the tropical forests of South America.

It is agreed by all anatomists, that, of all distinguishing characters, the *dentition* of an animal is one of the most important; so that, to see how widely apart the Old World and New World monkeys are, we have only to compare their teeth, with the following results:—

Dentition of Man and of Apes and Monkeys.

	Incisors.	Canines.	Premolars.	Molars.
1. *Man* and *Catarrhine Apes and Monkeys*,	$\frac{2}{2}$	$\frac{1}{1}$	$\frac{2}{2}$	$\frac{3}{3}$
2. *Platyrrhine Monkeys*,	$\frac{2}{2}$	$\frac{1}{1}$	$\frac{3}{3}$	$\frac{3}{3}$
3. *Marmosets*, . . .	$\frac{2}{2}$	$\frac{1}{1}$	$\frac{3}{3}$	$\frac{2}{2}$

We thus see that all the American monkeys differ widely, not only from man, but from all the apes and monkeys of the Old World. Whatever be the cause, this distribution of monkeys, like that of the humming birds, shows clearly that forces have been at work, developing in each great continent animal forms peculiar to itself, and differing from the animal forms developed by other continents.

The examples already given afford sufficient illustrations of the problems presented for solution by the facts of the geographical distribution of animals, and it is now time to give a brief systematic outline of the accepted zoological regions and of their sub-divisions. In doing this, I shall adopt the divisions of Mr. Wallace's Classical Work on the Distribution of

Animals,* confining myself to the distribution of the mammals, and simplifying, in some respects, the names of his zoological regions, so as to make them more readily understood by the general public.

The ancient land-systems of the globe are defined by the meridian axes of elevation described in pp. 20, 29; which date back as far as the earliest sedimentary deposits, modified, as in the case of Europasia, by an east and west small circle chain, which is only of Tertiary origin.

Of the meridian axes producing ancient land-systems, there are two in the northern hemisphere, and three in the southern hemisphere, as already described.

These ancient land-systems form five natural zoological regions, which may be named as follows:—

A.	*Europasian Region*, . .	*Palæarctic*† *Region.*
B.	*North American Region*,	*Nearctic*† *Region.*
C.	*South American Region*,	*Neo-tropical*‡ *Region.*
D.	*African Region*, . . .	*Ethiopian*§ *Region.*
E.	*Australian Region*, . .	*Australian Region.*

To these natural zoological regions it has been found necessary to add a sixth zoological region to include

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* *The Geographical Distribution of Animals*, &c., &c.: By Alfred Russel Wallace, 2 vols. 8vo. Macmillan and Co., 1876.

† As North America is *really* older than Europasia, these terms are not appropriate.

‡ This is scarcely an appropriate name for a region which contains all Patagonia and the Falkland Isles.

§ This is not a suitable name for a region that includes the whole of South Africa.

Hindustan and the western portion of the East Indies and its Archipelago—whose animals differ sensibly from those of the neighbouring Europasian and Australian regions.

F. *Oriental*, or *Supplemental Region*, } *Oriental Region.*

(A.) *The Europasian Zoological Region.*—This region contains the whole of Europe, Africa, and Arabia north of the Tropic of Cancer; the Arabian Sea forms its southern boundary in Beloochistan, eastward of which the southern boundary coincides with the watershed of the Indus, Ganges, and Brahmapûtra (excluding their river-basins), and its extension further to the eastward reaches the Yellow Sea, at Shanghai, embracing the lower two-thirds of the rain-basin of the Yang-tze-kiang.

This boundary line is in most places entirely physical, viz.: The Sahara, the Arabian desert, the Arabian sea, the Solyman range, the Hindoo Koosh, the Himalayas, and the Nanling range forming the southern water-shed of the Yang-tze-kiang.

The Europasian zoological region is subdivided into the following sub-regions:—

1. *Central and Northern Europe.*
2. *Siberian*, or *Northern Asia.*
3. *Mediterranean.*
4. *Manchurian.*

The most characteristic mammals of the Europasian zoological region are the following genera :—

1.	*Talpa*, ...	*Moles.**
2.	*Meles*, ...	*Badgers.*
3.	*Camelus*, ...	*Camels.*†
4.	*Capreolus*, . . .	*Roe Deer.*
5.	*Moschus*, ...	*Musk Deer.*
6.	*Poephagus*, . . .	*Yak.*
7.	*Rupicapra*, . . .	*Chamois.*
8.	*Saiga*, ...	*Tartary Antelope.*
9.	*Capra*, ...	*Sheep and Goats.*‡
10.	*Myoxus*, ...	*Dormice.*§
11.	*Lagomys*, ...	*Arctic Hares.*‖

* Fossil moles are found in Europe as far back as the Lower Miocene.

† The camels are a highly characteristic desert form, of the Europasian region, extending from the Sahara to Mongolia, as far as Lake Baikal. They are represented in the South American region by the llamas and alpacas, which are similarly characteristic of the deserts of South America. The oldest known fossil camels are found in the Miocene beds of North America, *Procamelus*, *Pæbrotherium*, and *Protomeryx*.

It is highly probable that the ancestors of the *Camelidæ* migrated northwestward, across the shallow bridge of Behring's Straits, producing the dromedary and Bactrian camel in Europasia; and also migrated southward, producing the llama and alpaca in South America.

‡ There are two outliers of this family outside the Europasian region: one, on the Neilgherries, in Southern India, and the other in the Rocky Mountains and California, in North America.

§ Extinct fossil dormice have been found as far back as the Upper Eocene of Europe.

‖ These animals range from the south of the Ural Mountains to Cashmere and the Himalayas, at heights from 11,000 to 14,000 feet, and northwards into the Arctic Regions. They are also found in the Rocky Mountains, in North America, from 42° to 60° lat. Fossil forms have been found in the Miocene of Europe.

Pre-Glacial Fauna of Europe.— Before leaving the zoological region of Europasia, it may be well to record the Pre-glacial Fauna of Europe, the part of the region best known to us.

We are able to show, that in the period immediately preceding the Glacial, and at a time when, probably, the temperature of Europe had cooled down from the tropical Eocene, through the sub-tropical Miocene and Pliocene periods, to a condition not far removed from our present climate, various forms of monkeys, hyænas, lions, horses, tapirs, rhinoceroses, hippopotami, elephants, mastodons, deer, and antelopes, in addition to almost all the animals now living in Europe, produced here a rich and varied Fauna, such as we now see only in the open country of tropical Africa.

How and why did this luxuriant Fauna disappear?

The answer to this question is two-fold—the destruction of the European Pre-glacial Fauna is due to the following causes, of which the first is certain, and the second hypothetical:—

1. The cold of the Glacial period compelled the animals either to perish, or to migrate southwards.

2. They were compelled to accept the first alternative, because the communication by land with Africa, which formerly existed by Gibraltar, and by Sicily and Malta,* had ceased.

(B.) *The North American Zoological Region.*—This region coincides nearly with geographical North America, omitting the tropical districts in the south, bordering on Central America.

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* *Vide* pp. 172, 173.

The living mammals peculiar to the North American region are not numerous, although its extinct mammals are the most abundant and varied of any as yet found in any country: the poverty in living mammalian types of North America is attributed to their destruction by the cold of the Glacial period.

The Glacial cold, as evidenced by the distribution of the *Drift*, affected the Eastern portion of North America, as far south as 39° N. Lat.

In Europe, the Drift deposits occur across the whole continent, as far south as 51° N. Lat., which corresponds to the same isothermal line as 39° N. Lat. in America.*

The North American zoological region is divided into the following sub-regions:—

1. *Californian.*
2. *Rocky Mountain.*
3. *Alleghanian.*
4. *Canadian.*

Two natural families are characteristic of the North American zoological region, viz.:—

1. *Saccomyidæ*, . . *Pouched Rats.*
2. *Haploodontidæ*, . *Californian Rats.*†

* It is a curious fact that, so far as we know, Siberia is free from *drift* deposits, or evidence of a Glacial period.

† These contain two curious rat-like animals ranging along the west coast of North America, from British Columbia to the mountains of California; they seem to have relationships both to *Beavers* and to *Marmots*.

Also, the following genera :—

3. *Antilocapra*, . . *Prong-horn Antelope.**
4. *Jaculus*, . . . *Jumping Mouse.*†
5. *Cynomys*, . . . *Prairie Dog.*‡
6. *Erethizon*, . . *Canadian Tree Porcupine.*

The foregoing rather poor list contains the mammals peculiar to the North American region; but further light is thrown upon the Fauna of the region by the following list, which shows the mammals now common in Europasia, that are absent from North America :—

Mammals common in Europasia, but absent from North America.

1. *Hedgehogs.*
2. *Horses and Asses.*
3. *Swine.*
4. *Goats.*
5. *Dormice.*
6. *Mice.*
7. *Sheep.*§
8. *Antelopes.*§

If we inquire into the condition of North America,

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* This solitary antelope of North America is an outlier, dwelling in both sides of the Rocky Mountains, and extending north to the Saskatchewan and Columbia river; west as far as the coast range of California, and east to the Missouri.

† This is a North American outlier of the Syrian jerboas.

‡ These are allied to the squirrels.

§ Represented by solitary species, only, in the Rocky Mountains.

in Pre-glacial times, we find a totally different state of affairs.

The Tertiary deposits of Western America form the best developed series of beds, of their age, known to geologists.

The fresh-water Eocene beds of the Western Territories are two miles in thickness, resting unconformably upon the Cretaceous beds. They are the remains of lake basins lying in elevated valleys westward of the main ridge of the Rocky Mountains, and eastward of the Wahsatch range, along the high central plateau of the continent.

Professor O. C. Marsh* gives the following account of their formation :—

"As these mountain chains were elevated, the enclosed Cretaceous sea, cut off from the ocean, gradually freshened, and formed these extensive lakes, while the surrounding land was covered with a luxuriant tropical vegetation, and with many strange forms of animal life. As the upward movement of this region continued, these lake basins, which for ages had been filling up, preserving in their sediments a faithful record of Eocene life-history, were slowly drained by the constant deepening of the out-flowing rivers, and they have since remained essentially dry land."

These Eocene beds are sub-divided into three :—

1. Lower Eocene, . *Coryphodon* Beds.
2. Middle Eocene, . *Dinoceras* Beds.
3. Upper Eocene, . *Diplacodon* Beds.

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* *Introduction and Succession of Vertebrate Life in America.* Address (1877).

The beds are so named from the most abundant and typical of their fossil remains.

Coryphodon is the type of a large family of odd-toed Ungulates, some of which exceeded the tapir in size; they were provided with large canine teeth; and are remarkable for the diminutive size of the brain,* which in size and form approaches that of the Reptiles; they also possessed five-toed fore and hind feet, the primitive type from which all the various forms of the mammalian foot have been derived. Specimens of a large *Coryphodon* have been found in Lower Eocene beds of Europe.†

Dinoceras is the type of a large family, related both to the odd-toed Ungulates and the Proboscideans. They nearly equalled the elephant in size, but had shorter legs; the skull was armed with two or three pairs of horn cores, and they had enormous canine teeth; the brain was so small, that it might easily have been pulled backwards, as far as the sacral vertebrae, through the spinal canal; there were five toes on the fore and hind feet; the head could reach the ground, and there is no indication of a proboscis.

Professor Marsh thinks it possible that the Proboscideans may be the much modified descendants of the *Dinocerata.*

Diplacodon was an odd-toed Ungulate, nearly as large as a rhinoceros.

The Miocene lake basins lie on the flanks of the region occupied by the Eocene beds, where only land had been since the close of the Cretaceous period.

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* The cerebellum nearly equals the united hemispheres in size.

† Prof. Marsh is of opinion that the Eocene, Miocene, and Pliocene beds of America are relatively older than those similarly named in Europe.

These basins contain three faunas, nearly or quite distinct, viz.:—

1. Lower Miocene, . *Brontotherium* Beds.
2. Middle Miocene, . *Oreodon* Beds.
3. Upper Miocene, . *Miohippus* Beds.

The climate during the whole of this period was sub-tropical or warm temperate.

Brontotherium represents a family of large animals, related to the *Dinocerata* and to the Proboscideans; they nearly equalled the elephant in size, with shorter legs; had only one pair of horn cores; the nose was probably flexible, without a proboscis; had four toes on the fore feet, and three toes on the hind feet.

Oreodon is the type of a family of ancestral pigs, aptly named by Prof. Leidy "ruminating hogs"; it was about as large as its descendant, the Peccary. They must have lived in large droves on the borders of the Miocene lakes, in which their remains have become entombed. They had four well-developed, useful toes, both on the fore and hind feet.

These animals probably bear the same relation to the modern even-toed Ungulates, that the animals already described bear to the modern odd-toed Ungulates.

Miohippus is one of the ancestors of the modern Horse, whose pedigree has been so admirably traced by Professor Marsh. The following is a brief sketch of his conclusions:—

Geological Pedigree of the Horse.

The oldest known ancestor is *Eohippus*, from the Lower Eocene or *Coryphodon* beds; of which several species have been found, all about the size of a fox; with four well-developed toes on the fore feet, with a rudiment of a thumb, and three toes on the hind foot.

The next ancestor is found in the Middle Eocene, or *Dinoceras* beds, and is called *Orohippus*, replacing *Eohippus*, and showing a further, though still distant, relationship to the Equine type; the rudimentary thumb has disappeared, and the last premolar tooth has gone over to the molar series. *Orohippus* was slightly larger than *Eohippus*, and lived on into the Upper Eocene, or *Diplacodon* beds, where it disappears.

A third ancestor makes its appearance in the Lower Miocene, or *Brontotherium* beds, and is called *Mesohippus*. It is about as large as a sheep, and is one stage nearer to the horse. There are only three toes, and a rudimentary splint bone on the fore foot, and three toes behind; and there are other indications of change in the dentition, and in the bones of the forearm and leg, pointing in the same direction.

Mesohippus disappears in the Upper Miocene beds, and gives place to the fourth ancestor, *Miohippus*, which is related to the *Anchitherium* of the Eocene beds of Europe. The three toes in each foot are more nearly of a size, and a rudiment of the thumb is still retained.

The next step is reached in the Lower Pliocene beds,* where *Protohippus* appears, some species of which attain the size of an ass. There are still three toes on each foot, but only the middle one reaches the ground. The *Protohippus* resembles closely the *Hipparion* of the Upper Eocene of Europe.

The sixth stage is reached in the higher Pliocene beds, and is called *Pliohippus*, which has lost the small hooflets, and is otherwise very equine.

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* During the Pliocene period, in North America, the climate was much the same as that of the Miocene period.

Finally, the true Horse (*Equus*) appears in the Upper Pliocene, and completes the genealogy of the horse, which in Post Tertiary times roamed over the whole of North and South America, and soon after became extinct.

There are now living, in a wild state, only the Ass and the Zebra to represent the *Equidæ;* the former ranging from North Africa and Syria to Western India, Mongolia, and Manchuria; and the latter confined to Africa.

Professor Marsh is of opinion that the *Rhinoceros*, and *Tapir*, as well as the *Horse*, derive their ancestry from fossil forms preserved in the North American Tertiary beds, but admits that the connecting links are not so clearly made out as in the case of the horse.

Pre-Glacial Fauna of North America.—If we compare the existing Fauna of North America with that of its Pre-glacial period, we find that the Glacial period has effected as great a destruction of mammalian forms as it produced in Europe.

The following types now confined to the Old World were destroyed, viz., horses, camels, and elephants; and in addition, the following types, belonging essentially to South America, perished—llamas, tapirs, capybaras, and gigantic Edentates.

The Old World forms were probably of indigenous growth, as we have already seen in the case of the horse and the camel, and were given to the Old World by North America, by migration *viâ* Behring's Straits.

Of the South American forms, now lost to North America, the gigantic Edentates have perished in South America itself, no doubt from the effects of the cold of the Glacial epoch of the southern hemisphere, of which evidence (drift and boulder clay) is found in South America as far north as 37° S. Latitude, and in New Zealand at 40° S. Lat.

The Glacial period of the southern hemisphere was, in all probability, contemporaneous with that of the northern, and both had their common cause in a cosmical phenomenon, viz., the *diminished heat radiation of the Sun.*

All the evidence as yet obtained from the southern hemisphere goes to show that the Eocene climate was tropical there, and the Miocene climate sub-tropical, as in the northern hemisphere.* Mr. Wallace adopts the opinion that the arctic and antarctic Glacial periods were simultaneous, but with it he also adopts Mr. Belt's view—"that the warmer climates in past geological epochs, and especially that of the Miocene as compared with our own, was caused by a diminution of the obliquity of the ecliptic, leading to a much greater uniformity of the seasons for a considerable distance from the equator, and greatly reducing the polar area within which the sun would ever disappear during an entire rotation of the earth. During such a period, tropical forms of marine animals would have been able to spread north and south, into what are now cool latitudes; and identical genera and even species might then have ranged along the southern shores of the old

* Professor M'Coy found abundant marine fossils of Eocene and Miocene age in Victoria, Lat. 37° S., which are strikingly like those of Europe at the same periods; amongst them *Volutes* closely allied to those of the Eocene beds of the Isle of Wight. With extinct species found in the Eocene and Miocene beds are associated some living species, but *always* such as now live farther north in tropical seas. These facts all point to the *Hypothesis of a cooling globe with fixed axis of rotation.*

Palæarctic continent, from Britain to the Bay of Bengal, and southward along the Malayan coasts to Australia."*

(C.) *South American Zoological Region.*—The South American zoological region is much richer in peculiar types than either the Europasian or North American regions.

The following summary of the peculiar families of Mammals, is given by Mr. Wallace :—

1.	*Cebidæ*, ...	*South American Monkeys.*
2.	*Hapalidæ*, . . .	*Marmosets.*
3.	*Phyllostomidæ*, . .	*Leaf-nosed Bats.*†
4.	*Chinchillidæ*, . .	*Chinchillas* and *Viscachas.*
5.	*Caviidæ*, ...	*Cavies* and *Agoutis.*
6.	*Bradypodidæ*, . .	*Sloths.*
7.	*Dasypodidæ*, . . .	*Armadilloes.*
8.	*Myrmecophagidæ*, .	*True Ant-eaters.*

In addition to these families, there are many peculiar genera, too numerous to mention.

With regard to the predecessors of the existing South American Fauna, Mr. Wallace says :—

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* This is a pretty picture, and it is a pity that the cruel mathematicians step in, with their hard logic, to spoil it. The fact however is, that the mathematicians forbid, on mechanical grounds, the use of the two following playthings to the geologists :—

1. The shifting of the axis of rotation inside *the body of the earth.* No known geological displacement of rock masses will account for a displacement of more than from 1° to 3°; or less than 200 miles.

2. The shifting of the axis of rotation *in space.* Mr. Belt's theory requires this, which is still less admissible than a shifting inside the body of the earth.

† These include the celebrated blood-sucking vampire bats.

"Abundant remains of the Post-pliocene period from Brazilian caves show us that the Fauna of South America, which immediately preceded that now existing, had the same general characteristics, but was much richer in large Mammals, and probably in many other forms of life. *Edentates* formed the most prominent feature; but instead of the existing sloths, armadilloes, and ant-eaters, there was an immense variety of these animals, some of living genera, others altogether different, and many of them of enormous size. There were armadilloes as large as the rhinoceros, while the *Megatherium*, and several other genera of extinct sloths were of elephantine bulk. The peculiar families of south American Rodents—cavies, spiny-rats (*Coypus*), and chinchillas—were represented by other species and genera, some of large size; and the same may be said of the Monkeys, Bats, and Carnivores. Among the Ungulates, however, we find, in addition to the living tapirs, llamas, peccaries, and deer, several species of horse and antelope, as well as a *Mastodon*, all three forms due probably to recent immigration from the northern continent."

This remarkable intermixture of South American and North American types (the former greatly preponderating) leads us to believe that the land bridge that now connects North and South America was formed in Pre-glacial times, and allowed the *Megatherium* and *Megalonyx* to enter North America from the south, while the horse, deer, *Mastodon*, and most of the Carnivores entered South America from the north.

This view is supported by the curious fact, that a large number of marine fishes of the two sides of Central America are absolutely identical.

It seems almost impossible to account for the strong contrast between the Faunas of North and South America, without supposing a similar contrast between the animal types produced in the arctic and antarctic areas, when the cooling of the globe allowed animal and vegetable forms to make their first appearance in the neighbourhood of each pole.*

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* Buffon, the inventor of the hypothesis of a *cooling globe with fixed axis*, strangely overlooked the effects of his hypothesis in the southern hemisphere. He says:—

"Ainsi, dès l'origine et dans le commencement de la Nature vivante, les terres les plus élevées du globe et les parties de notre *Nord* ont été les premieres peuplées par les espèces d'animaux terrestres auxquels la grande chaleur convient le mieux: les regions de l'équateur sont demeurées longtemps désertes et même arides et sans mers." (*Œuvres complètes de Buffon:* (1817). Vol. ii., pp. 485–6.) Again:—

"Les régiones *Septentrionales*, et les parties les plus élevées du globe, et surtout les sommets des montagnes dont nons avons fait l'enumération, et qui, pour la plupart, ne présentent aujourd'hui que des faces sèches et des sommets stériles, ont donc autrefois été des terres fécondes, et les premières où la Nature se soit manifestée, parce que ces parties du globe ayant été bien plus tôt refroidies que les terres plus basses on plus voisines de l'équateur, elles auront les premiéres reçu les eaux de l'atmosphère, et toutes les autres matières qui pouvoient contribuer à la fécondation." (Vol. ii., p. 486.)

Buffon was no believer in the absurd dogma of some modern Naturalists—*omne vivum ab ovo*—which, when pushed to its logical *reductio ad absurdum*, has led to the puerile conceit of the origin of life on our globe having been a germ travelling on a meteoric stone.† On the contrary, Buffon evidently believed that when certain (no doubt definite, and pre-arranged, although) unknown physical conditions are fulfilled, organic life, both vegetable and animal, will make its appearance, and run through a course of development, in which the chief factors are:—

1. *Heat.*

"La même température nourrit, produit partout les mêmes êtres."‡ (Vol. ii., p. 366.)

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† Where and how did the meteoric stone become possessed of this precious germ?

‡ He modifies this too general statement afterwards, when speaking of the singular difference between the animals of the New and Old Worlds.

Mr. Wallace subdivides the South American zoological region into the following sub-regions:—

1. *Chilian.*
2. *Brazilian.*
3. *Mexican.*
4. *Antillean.*

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2. *Moisture and other physical conditions.*

"Voyons donc pourquoi il se trouve de si grands reptiles, de si gros insectes, de si petits quadrupèdes, et des hommes si froids dans ce Nouveau Monde. Cela tient à la qualité de la terre, à la condition du ciel, au degré de chaleur, à celui d'humidité, à la situation, à l'élévation des montagnes, à la quantité des eaux courantes ou stagnantes, à l'étendue des forêts, et surtout à l'état brut dans lequel on y voit la nature. La *chaleur* est en général beaucoup moindre dans cette partie du monde, *l'humidité* beaucoup plus grande." (Vol. vi. p. 521.)

3. *Migration* (with *Isolation*).

Speaking of the Leopard, Jaguar, and Puma, Buffon says:—

"Par exemple, la *Panthère* de l'Afrique diffère moins du *Jaguar* du Brésil que celui-ci ne diffère du *Couguar* (*Puma*) qui cependant est du même pays. . . . . On pourroit donc croire, avec assez de fondement, que ces animaux ont eu une origine commune, et supposer qu'ayant autrefois passé d'un continent à l'autre, leurs différences actuelles ne sont venues que de la longue influence de leur nouvelle situation." (Vol. viii. p. 313.)†

4. *Degradation.*

Buffon held, strongly, the same idea with regard to animals that Linnæus did with regard to plants, viz., that the older types were more highly organized, and became degraded in process of time.

On the whole, Buffon's works offer a promising field for the researches of plagiarists, for they are full of original and good ideas, and are now read only

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† In speaking of the animals *common* to the two hemispheres, Buffon makes the very remarkable statement:—" On ne peut cependant se refuser à les regarder comme les mêmes, et à croire qu'ils ont autrefois passé de l'un à l'autre continent par des terres du Nord, peutêtre encore actuellement inconnues, on plûtot anciennement submergées; et *cette preuve, tirée de l'histoire naturelle, démontre mieux la contiguité presque continue des deux continents vers le Nord, que toutes les conjectures de la géographie spéculative.*" (Vol. vi. p. 515.)

(D.) *The African Zoological Region.*—The Fauna of Africa tells the same story as that of South America, and, like it, points to a southern origin in antarctic lands, in former times, modified by immigrations from the Europasian region. It also shows, as already mentioned, a remote former connexion with South America, as evidenced by the close relationship of the ostrich to the rhea, and by the occurrence of ant-eaters closely related to those of South America.

The following, among other families of mammals, are peculiar to the African region :—

1. *Protelidæ*, . . .	Aard Wolf.*
2. *Hippopotamidæ*, .	Hippopotamus.
3. *Camelopardalidæ*, .	Cameleopard.
4. *Orycteropodidæ*, .	Aard-vark, or Cape Ant-eaters.
5. *Chiromyidæ*, . .	Aye-aye.†
6. *Centetidæ*, . . .	Madagascar Hedgehogs.‡

In addition to the families peculiar to the African region, there are many highly characteristic genera—

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by a few, who probably would not take the trouble to strip an ass of his lion's skin. Several modern books of geology and physical geography, of good repute, are mere expansions of Buffon, and it is remarkable how seldom he is quoted in their pages.

To these causes of Variation and Development, must be added a fifth, discovered and wonderfully illustrated by Darwin, viz. :—

5. *Competition with other animals, leading to survival of the Fittest.*

No Naturalist, well acquainted with Buffon's writings, can have a high opinion of the originality of Lamarck's speculative views as to the development of animals.

* A highly modified Hyæna, approaching the Ichneumon, and feeding on white ants and carrion.

† Peculiar to Madagascar.

‡ It is very remarkable, that two species are found in the West Indies, one in Cuba, and the other in Hayti.

especially of baboons, monkeys, apes, lemurs, peculiar swine, and a greater variety of antelopes than is found in any other zoological region. The African zoological region is also very remarkable for the absence of such widespread families as bears and deer.

The bears range over the whole northern hemisphere, and as far south as Sumatra in the eastern and as far south as Chili in the western hemisphere; yet they are totally wanting in tropical and southern Africa.

The deer, which are still more widely distributed than the bears (ranging over all North and South America, and over all Europasia), are totally absent from the African region. Goats, sheep, the true ox and true pig, are also wanting. The following explanation of the peculiar fauna of the African region may be offered:—

We have evidence to show, from the prevalence of lower Tertiary fossils* over the Sahara, parts of Arabia, Persia, and northern India, that an east and west sea at that time stretched from the Bay of Bengal to the Atlantic, cutting off India and Ceylon, as well as the African region, from Europasia. Subsequently, and down to a recent period, North Africa and Europe were united by two land bridges, at Gibraltar and *viâ* Sicily and Malta.†

While Africa was cut off from Europasia, it is not improbable that it extended further southwards (possibly having had in former times connexion with South America through the Antarctic continent), and derived its peculiar fauna from that southern extension. The ancient and peculiar fauna of the African region, derived from the southern hemisphere, is now represented by its

* Especially the Nummulite limestone.

† *Vide* pp. 172, 173.

edentates, lemurs, and insectivores, and possibly by many other forms now extinct, but which in time may be discovered (as in South America) by researches among the African Tertiary rocks.

Mr. Wallace so well describes the subsequent invasion of Africa from the north, that I prefer giving his own words:—

"All the great Mammals which now seem so specially characteristic of Africa—the lions, leopards and hyænas—the zebras, giraffes, buffaloes, and antelopes—the elephants, rhinoceroses, and hippopotami—and perhaps even the numerous monkeys, baboons, and anthropoid apes—are every one of them comparatively recent immigrants who took possession of the country as soon as an elevation of the old Eocene and Miocene sea-bed afforded a passage from the southern borders of the Palæarctic region. This event probably occurred about the middle of the Miocene period, and it must have effected a great change in the fauna of Africa. A number of the smaller and more defenceless of the ancient inhabitants must have been soon exterminated, as surely as our introduced pigs, dogs, and goats exterminate so many of the inhabitants of oceanic islands; while the new comers, finding a country of immense extent, with a tropical climate, and not too much encumbered with forest vegetation, spread rapidly over it, and thenceforth greatly multiplying, became more or less modified in accordance with the new conditions. We shall find that this theory not only accounts for the chief *specialities*, but also explains many of the remarkable *deficiencies* of the fauna. Thus, bears and deer are absent, because they are comparatively late developments, and were either unknown or rare in Europe till late Miocene or Pliocene times; while, on the other hand, the immense area of open tropical land in Africa has favoured the preservation of numerous types of large mammals which have perished in the deteriorated climate and diminished area of Europe.

"Our knowledge of the geology of Africa is not sufficiently detailed to enable us to determine its earlier history with any approach to accuracy. It is clear, however, that Madagascar was once united with the southern portion of the continent, but it is no less clear that its separation took place before the great irruption of large animals just described; for all these are wanting, while lemurs, insectivores, and civets abound, just the low types which were once the only inhabitants of the main land."*

The African zoological region is subdivided into the following sub-regions—

1. *East African.*
2. *West African.*
3. *South African.*
4. *Malagasy.*†

(E). *The Australian Zoological Region.*—The *Australian* zoological region includes Australia, New Zealand, Papua, Gilolo, Celebes, and the East Indian Archipelago, as far west as the Strait of Lombok, together with a large portion of Polynesia. It appears to be the remains of a large continent, formed by the East

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* *Proceedings R. G. S.*, vol. xxi., pp. 516, 517.

† This sub-region, including Madagascar and the Mascarene Islands, is one of the most remarkable in the world, and is probably one of the oldest.

Australian Meridional Chain;* and it is probable that, like Africa and South America, it formerly extended much further south, even as far as the Antarctic Continent.

The Australian zoological region is subdivided by Mr. Wallace into the following sub-regions:—

1. *Austro-Malayan.*
2. *Australian.*
3. *Polynesian.*
4. *New Zealand.*

This zoological region is the most remarkable in the world, not even excepting South America. It is characterized by the almost complete absence of placental mammals, which are only represented by a few bats and rodents, the latter of small size (*Muridæ*).

The non-placental mammals are so peculiarly Australian, that I have already, practically, given a summary of the Australian region in discussing the distribution of this group of mammals.†

(F). *The Oriental or Supplemental Zoological Region.*— This zoological region contains all tropical Asia, east of the Indus, with the Malay islands as far as Java, Borneo, and the Philippines.

I have called it a Supplemental region, as it does not owe its origin or fauna to any of the primary continents of the northern or southern hemisphere, but seems to have been supplied by immigration.

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* *Vide* p. 20. † *Vide* pp. 266 and 267.

Its peculiar families of mammals are few in number and limited in extent. They are—

1. *Galeopithecidæ**—Flying Lemurs.
2. *Tarsiidæ*.†
3. *Tupaiidæ*.‡

The Oriental zoological region possesses a considerable number of peculiar genera, highly characteristic of the region; including apes, monkeys, and lemurs, civets and weasels, mouse deer (Chevrotain), and a few peculiar antelopes and rodents.

On the whole, the Oriental region must be regarded as poor in peculiar forms of mammals; and its supplemental character is well shown by the fact that it contains representatives of all the important families of the Europasian region, except that of the dormice (*Myoxidæ*).

On the other hand, the birds of the Oriental region are highly characteristic and peculiar. There are about 350 genera of land-birds, of which nearly one-half are peculiar to the region.

The Oriental zoological region is subdivided into the following sub-regions—

1. *Indian.*
2. *Ceylonese.*
3. *Indo-Chinese.*
4. *Indo-Malayan.*

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* This remarkable family is regarded by Mr. Wallace as a lateral offshoot of some low form, which has survived during the process of development of the Lemurs, Insectivores, and Marsupials, to all of which it is related.

† The *Tarsier*, which constitutes this family, is a small, long-tailed, nocturnal animal, of curious structure and appearance, allied to the Lemurs.

‡ These are squirrel-like shrews, having bushy tails, and often climbing up trees, but also feeding on the ground and among low bushes.

The first two of these sub-regions, as already stated,* were separated from the Europasian region during the greater part of the Tertiary period; and of the two sub-regions, the Ceylonese, consisting of Ceylon and Madras as far as the Neilgherry Hills, is much older than the rest of the Hindustan Peninsula, as is evidenced by its backbone of granite and metamorphic rocks.

It is remarkable that Ceylon, the oldest part of the Oriental region, shows evidence of a connexion with Madagascar, before the latter island had parted company with Africa.

There are in Madagascar six genera of lemurs, containing thirty-four distinct species; in Ceylon and Southern India, we have a single species of the *Loris*, a small, tailless, nocturnal lemur.

The extreme antiquity of the Lemuroid fauna is shown by the facts that outlying lemurs are found in West and South Africa, and in Eastern Bengal, Java, and South China. Of these outliers, two species belong to West Africa, fourteen to tropical and South Africa, and three species belong to Bengal, Java, and China.

From these facts the obvious inference is, that the lemurs once ranged (when Madagascar was united to Africa) from Africa along the southern shores of Europasia, then probably extending so far south as to make the East Indian Archipelago a part of the Asiatic Continent. Afterwards, when Europasia was joined to Africa and India, the isolated lemurs which remained were saved from destruction by their insular and exceptional position.

The distribution of the scaly ant-eaters (*Manis*) furnishes

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* *Vide* p. 291.

us with another proof of the former connexion of Ceylon with Africa on the south-west, and with China on the north-east.

Four species of scaly ant-eaters are found in East, West, and South Africa, while two species are found in Ceylon, Java, Nepaul, and South China.

These remarkable edentates are the remains of a migration eastwards and northwards from Africa, and possibly their ancestral home is to be found in the extended antarctic continent that once united the southern portions of Africa and South America.*

The Geographical Distribution of Plants.—In sketching the geographical distribution of plants, I shall follow the guidance of Bentham, who recognizes only three great floras at present existing.† These three floras are—

(A). The *Northern Flora.*
(B). The *Southern Flora.*
(C). The *Equatorial-Tropical Flora.*

(A). *The Northern Flora.*—This flora corresponds in area with the whole of the vast regions contained in the Europasian and North American zoological regions—or, in other words, with the entire of the extra tropical lands of the northern hemisphere.

It is characterised by pine trees, catkin-bearing plants with deciduous leaves, and a vast profusion of herbaceous

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* It is worthy of note, that the wonderfully developed flora of South Africa, remarkably specialised, also points to the former existence of an extensive sub-tropical land, south of the Cape of Good Hope.

† He further considers these three floras as probably only geographical varieties of one very ancient flora.

plants covering the plains and uplands, such as *Ranunculaceæ, Cruciferæ, Leguminosæ.*

Among the most characteristic of the pine trees the following may be noted:—

Characteristic Conifers.

1.	*Abies*, ...	Silver Firs.
2.	*Picea*, ...	Spruce Firs.
3.	*Tsuga*, ...	Hemlock Spruces.
4.	*Cedrus*, ...	Cedars.
5.	*Pinus*, ...	True Pines (nearly all).
6.	*Larix*, ...	Larches.
7.	*Taxus*, ...	Yews.
8.	*Torreya*, ...	China and Japan, and California and Florida.

The foregoing eight genera are met with both in Europasia and in North America. The following are more limited in their distribution:—

9.	*Salisburia*, . . .	Japan.
10.	*Glyptostrobus*, . .	China.
11.	*Cephalotaxus*, . .	China and Japan.
12.	*Sequoia*, ...	California.
13.	*Taxodium*, ...	Eastern and Southern States of N. America and Mexico.
14.	*Thuja*, ...	Florida and California.
15.	*Callithrix*, ...	North Africa.

The great northern Flora is sub-divided into the following secondary floras:—

1. The *Arctic-Alpine.*
2. The *Temperate*, or *Intermediate.*
3. The *Mediterraneo-Caucasian* and *Chino-Japanese.*

1. The *Arctic-Alpine* region includes the Arctic regions north of the Tree-line, which are characterized by the following conditions:—

(*a*). The shortness of the period of vegetation;

(*b*). The lowness of temperature during that period.

In consequence of these conditions, annual plants are almost entirely wanting, and the vegetation consists mainly of perennial herbs and shrubs, with mosses and lichens. The chief families are:—

1.	*Grasses*, ...	10 per cent.
2.	*Sedges*, ...	10 „
3.	*Cruciferæ*, ...	8 „
4.	*Caryophyllaceæ*, ...	7 „
5.	*Ranunculaceæ*, ...	5 „
6.	*Rosaceæ*, ...	5 „
7.	*Saxifragaceæ*,*	5 „
8.	*Ericaceæ*, ...	5 „
9.	*Compositæ*, ...	4 „

In Siberia, in this region, broad flat plains occur covered with mosses, which are called moist *Tundras;*

* With fine flowers.

also, similar plains of decomposing granite, clothed with black, grey, or yellow lichens, affording food for animals: these are called dry *Tundras.*

The *Alpine** Flora occupies the extension southwards of the Arctic regions, along the ridges of lofty mountains, whose altitude produces conditions of climate similar to those caused in the Arctic region by latitude. For example, in Switzerland, the range in height from 3000 feet to 6000 feet corresponds to the range from 60° to 70° N. latitude.

2. The *Northern Intermediate,* or *Temperate* Flora, occupies the forest regions of the Old and New Worlds,

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* The *Alpine* Flora contains no genus more characteristic than *Saxifrage,* whose species are thus distributed among the more important districts:—

Saxifrage.

Districts.	Number of Species.
1. Alps,	43 Species.
2. Carpathians,	24 ,,
3. Pyrenees,	30 ,,
4. Caucasus and Armenia,	13 ,,
5. Himalaya,.	38 ,,
6. Altai,	25 ,,
7. Rocky Mountains,	24 ,,
8. Andes,	10 ,,
9. Arctic Region,	25 ,,

It is remarkable that the Flora of the Alps is more closely connected with that of the Altai ranges than with that of any other Alpine or Arctic floras, notwithstanding the great space of lowland that separates them, and the wide differences in their climatal conditions. Thus, fully 25 per cent. of the Alps species are present in the Altai region, and five-sixths of the genera. In fact, out of 12 Alps species, 3 will be found in the Altai, and only 2 species in the Caucasus, which is so much nearer.

Of the entire number of species of plants included in the Flora of the Alps, 17 per cent. are common to the Arctic flora, and 25 per cent. are common to the Altai range.

also the Steppe region in Europasia, and the Californian and Prairie regions of North America.

The *Europasian Forest* region is characterized by a pretty uniform temperature during the vegetative season, and by the absence of a rainless season. Its chief forest trees are chestnut, oak, beech, birch, spruce fir, and larch. Its meadows are clothed with turf-forming grasses, and it contains heaths and mosses, with alder fens, almost peculiar to the region. Its cultivated products include potato, apple, vine, wheat, oat, rye, and barley: of these the barley grows in the northern, and the apple and vine in the southern portions of the region.

The *Steppe* region is characterised by a severe protracted winter, a short spring, and a rainless, burning summer, succeeded almost immediately by the snow of winter. Its flora is characterized by bulbous plants and those yielding volatile oils, or covered with hairs and spines; trees and shrubs occur only where there is abundance of water. Its cultivated products are rice and cotton, and fruit trees, if protected in winter.

The *North American Forest* region resembles in its general characters the Europasian forest region. In the north, *Picea alba* and *Picea nigra* replace the Europasian firs; and among its deciduous trees, the species of oak, beech, elm, ash, and maple are different from those of Europe. In the south, evergreen exogenous trees abound, and special genera of *Compositæ*, such as *Aster* and *Solidago* (Golden rod).

The *Californian* region occupies a long narrow stripe extending along the western coast, and is characterized by a remarkably uniform temperature.* The summer is rainless, and the whole climate resembles that of the Mediterranean, but is cooler.

The Flora is remarkable for the following forms:—*Sequoia*, or "big-trees," oak, ash, willow; evergreen exogenous trees, and shrubs allied to oleander and myrtle, with only a few asters and golden rods.

The absence of the following forms is also remarkable:—magnolias, tulip trees, locust trees, hickory, elm, mulberry, holly, lime trees, beech, chestnut, hornbeam, clethra and birch. Among herbs and shrubs, the lobelias and kalmias are absent.

The *Prairie* region is characterized by treeless plains, and has a cold severe winter, followed by a short period of active growth, with a rainy season; then a dry rainless summer.

The south-western portion is a salt desert, marked by the abundance of *Chenopodiaceæ* (Goosefoot) and *Artemisiæ*.

The northern portion is a grass steppe, and the southern portion is characterized by agaves, aloes, yuccas, and cactuses.

The few trees and shrubs that occur have migrated from the north *forest* region.

3. The *Mediterraneo-Caucasian* and *Chino-Japanese* region extends eastwards to the borders of India, where it stops, and the temperate and tropical regions come into abrupt contact, being separated only by the great east and west mountain chain of Asia. After a long gap, some of the Mediterranean forms appear again in China.

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* The summer and winter temperatures differ only by a few degrees (11° to 14° F.).

The *Mediterraneo-Caucasian* region is characterized by a mild winter and rainless summer; hence plants grow in spring, remain stationary in summer, and again grow in autumn. It contains a great abundance of evergreen trees, laurel, myrtle, oleander, olive, evergreen oak, and thorny shrubs covering wide tracts and forming dense thickets.* The following products are cultivated:—olive, vine, mulberry, maize, millet, rice, water-melon, fig, cotton, date-palm, banana, and sugar-cane.

The *Chino-Japanese* region is characterized by a moderate temperature and an abundant rainfall equally diffused. The country has been so long under cultivation, that many of its natural characteristics have been obliterated. It contains many evergreen trees and shrubs, such as *Camelliaciæ* (tea family), *Magnolia*, *Euonymus* (spindle tree), *Aucuba* (spotted laurel), and others. Its cultivated products are: wheat, cotton, indigo, sugar-cane, orange, rice, tea, and mulberry.

The Flora just described follows the line of the great east and west mountain chain of Europasia. During the Eocene period, a deep sea occupied the place of the Europasian axis, extending from the Pyrenees to Japan.† During the Miocene period, it is probable that this axis was gradually converted from sea into dry land; and during the Pliocene period, although it formed land, it was not a lofty mountain chain. During that period, an uniform flora must have occupied a broad band of latitude, extending longitudinally from the Pyrenees to the east coast of China, upwards of 8000 miles. The subsequent elevation of the central portion of the axis divided

* In elevated regions, high up, we find the cedar (*Cedrus*).

† *Vide* pp. 52, 53.

the flora into a western sub-flora, *Mediterraneo-Caucasian*, and an eastern, *Chino-Japanese*, the central portion being destroyed, and in its place the temperate and tropical floras meet abruptly along the axis of the Hindoo Koosh and Himalaya ranges.

(B). *The Southern Flora.*—The Flora of the antarctic and temperate regions of the southern hemisphere occupies scattered and detached portions of land, often widely separated from each other by deep intervening oceans, and shows many signs of local influences modifying the plants. In the southern region we do not meet so much with similar species and genera, as with representative forms. The following families are characteristic :—

1. *Restiaceæ.**—Rush and sedge-like plants, but differing essentially in structure from *Cyperaceæ*, which is a Northern Hemisphere family. Australia, South Africa, and Chili.

2. *Proteaceæ.*—A large family of shrubs and trees peculiar to the Southern Hemisphere. They constitute from 8 to 12 per cent. of the flora of Australia, and from 2 to 6 per cent. of the flora of the Cape. A few are found in South America.

3. *Epacridaceæ.*—A southern family allied to *Ericaceæ* (heaths), but differing in structure, occurs in Australia and New Zealand.

4. *Mutisiaceæ.*—A sub-division of the *Compositæ*, peculiar to the Southern Hemisphere; formed of shrubby climbers, with leaves ending in tendrils.

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* A few plants of this order have been recently (1879) found in Cochin China.

5. *Mesembrianthemaceæ.*—Fig marigold family, found abundantly in arid situations at the Cape; also occurs in New Zealand.

In addition to the foregoing Families, the *Geraniaceæ* and *Ericaceæ*, although represented in the northern hemisphere by a few wide-spread species, obtain their full and luxuriant development in the southern hemisphere.

The following important genera are also highly characteristic of the southern Flora:—

1. *Araucaria.*—Norfolk Island pine, found in South America, Australia, New Caledonia, New Hebrides, Norfolk Island.

2. *Dammara.*—One of the conifers: Australia, New Zealand, Fiji, New Caledonia, New Hebrides, Moluccas, and Philippine Islands.

3. *Phyllocladus.*—One of the conifers: Tasmania, New Zealand, and Borneo.

4. *Podocarpus.*—A conifer, allied to the yew: New Zealand, Australia (?), Japan-China, Tropical Asia.

The *Southern Flora* is subdivided into the following Floras:—

1. *Antarctic—Alpine.*
2. *Temperate South American.*
3. *South African.*
4. *Australian.**

* Including New Zealand and the neighbouring islands.

1. The *Antarctic Flora.*—Of the scanty vegetation of the ice-bound antarctic continent but little is known.

Cape Horn lies about 500 miles north of Louis Philippe Land, which is the nearest part of the antarctic continent.

Kerguelen's Land lies about 1000 miles north of Enderby Land, the nearest point of the antarctic continent; and is 2170 miles from the Cape, 3800 miles from New Zealand, and 4100 miles from Cape Horn.*

The flowering plants are eighteen in number, of which two genera are peculiar to the island, viz., *Pringlea antiscorbutica,* Kerguelen's Land cabbage, a gigantic cruciferous plant, and a genus *Lyallia,* which has decided relations to Andean forms.

I now quote Dr. Hooker's words:—†

"Of the remaining sixteen flowering plants, four are peculiar to Kerguelen's Land, but *three* of them are so nearly allied to Terra del Fuego congeners, that they may equally rank as varieties of these, and the fourth stands in the same relation to a New Zealand plant. Of the remaining twelve, *ten* are Fuegian, of which *four* are confined to Fuegia and Kerguelen's Land, including the remarkable umbelliferous plant (*Azorella Selago*), which belongs to a group that is otherwise very characteristic of the South American Andes. Five are found in all circumpolar regions, and one alone is confined to Kerguelen's Land and Lord Auckland's group (south of

* It may be remarked that the great circle joining Kerguelen's Land with Cape Horn passes nearly through the South Pole; from which, probably, both obtained their original flora.

† Hooker, Lecture on Insular Floras, British Association Meeting, Nottingham, 1866.

New Zealand). Three are European, and all of these are common English and antarctic water-plants: viz.—

Callitriche verna.

Limosella aquatica.

Montia fontana.

"The affinity of the Kerguelen's Land flora is hence extremely close to the Fuegian; so close, indeed, that it cannot be doubted that it was for the most part derived from thence.* And, it is all the more remarkable, that this relationship should be so strong and unmistakeable, if you consider that the mother country of its flora is not that which is nearest to it [as was the case with all the other islands we have discussed], but that which is the most distant from it; and indeed Kerguelen's Land is more distant from a continent than any other island in the Atlantic or Indian Oceans."

Kerguelen's Land is, in reality, no exception to Hooker's law of Insular Floras; for although it is 4100 miles distant from Cape Horn, of these only 1500 miles are water, the remainder being antarctic continent. In order to explain the botanical relation of Cape Horn to Kerguelen's Land, we have only to suppose (as was certainly the case when large exogenous trees flourished in Kerguelen's Land) a mild climate in the antarctic continent, to supply the necessary plants to Cape Horn, across 500 miles, and to Kerguelen's Land, across 1000 miles of ocean.

* Or both were derived from the South Pole, in Pliocene times, when the antarctic land had a genial climate and was a fruitful mother of plants and animals.

2. *Temperate South American Flora.*—This region includes not only the temperate zone of South America, but the ridges of the Andes almost up to the Gulf of Mexico. It is closely related to the New Zealand flora by *Fuchsia* and *Calceolaria*, among other remarkable genera, and by the fact that 12⅓ per cent. of the flora of New Zealand is also South American. These facts are most easily explained by supposing a former connexion of New Zealand with Wilkes's Land, the nearest point of the antarctic continent, a distance of less than 1500 miles, and having the Auckland Islands, the Macquarrie Islands, and Campbell Island as stepping-stones, pointing out the former course of the land bridge, at a time when the antarctic continent, like the arctic archipelago, enjoyed a mild climate. The facts of natural history (as Buffon has well remarked) teach us more of prehistoric geography than the speculations of chartographers or the dreams of the poets about Atlantis and Hy Brazil.

The *South American Temperate Flora* is also related to that of South Africa by the remarkable family of *Mutisiaceæ*, a division of *Compositæ*, formed of climbing plants with leaves ending in tendrils.

The facts of botany therefore confirm the inferences from the geographical distribution of the *Struthionidæ*, which shows, by means of the rhea and ostrich, an old relationship between South America and Africa.*

3. The *South African Flora* is most abundant, more so than that of any other region of the globe, and is characterized by the extraordinary variety of the following

* It would be easy to connect the Cape with Kerguelen's Land, *via* Prince Edward's Island and the Crozet Islands.

families, viz., *Ericaceæ*, *Proteaceæ*, *Euphorbiaceæ*, *Mesembrianthemaceæ*, *Compositæ*, *Liliaceæ*, *Irideæ*, and others.

The *South African Flora* shows a very remote (in time) connexion with Australia, but is much more closely related to New Zealand; thus, of 303 genera of flowering plants found in New Zealand, no less than 174 are found also in South Africa. The *South African Flora* has, as might be expected, many relations to Western Europe and Northern Africa, through the *Leguminosæ*, *Ericaceæ*, *Lobeliaceæ*, and other families and genera, such as *Gladiolus*.

It is also related to the flora of Eastern Africa by means of the sub-Alpine vegetation of Kilima-Njaro.*

4. The *Australian Flora* has for its chief features the prevalence of forms of *Eucalyptus*, *Proteaceæ*, *Epacridaceæ*, *Xanthorrhoœ* (King-grasses), *Acacia*,† and *Casuarina* (Beef-wood). New Zealand has most of its genera repeated in Australia, but has no *Eucalyptus*, *Acacia*, *Casuarina*, and no Australian species of *Proteaceæ*.

As already mentioned, the Australian Flora shows a very remote connexion (in time) with Africa. It has also an ancient connexion with tropical Asia, shown by the fact that identical or closely-related species occur in tropical Asia, and tropical and eastern sub-tropical Australia.

There also exists an ancient connexion of the mountain flora of Victoria and Tasmania with the southern extra-tropical region extending through New Zealand to the

* Hooker has shown that a Mediterranean leguminous plant, *Adenocarpus*, is found in Kilima-Njaro; and also in the Cameroons Mountains, 2000 miles west, and on the opposite side of the Continent.

† These are to be carefully distinguished from the northern hemisphere *Robinea*, as there are only a few *Acacias* in the north, e.g. *Acacia Arabica*.

Antarctic and South American Continents, and thence up the Andes.

There are no Bamboos in Australia, and no Equisetaceæ either in Australia or New Zealand.

The chief positive characteristic of the flora of Australia is, however, the large number of endemic forms, that is to say, forms peculiar to the country, and which have never spread.

The flowering plants of New Zealand contain 303 genera and 935 species. Of these 303 genera,

252	genera are common to			Australia,
174	„	„	„	South Africa,
115	„	„	„	Europe;

and of the 935 species*—

677	species are peculiar to			New Zealand,
222	„	are common to		Australia,
111	„	„	„	South America,
58	„	„	„	Europe.

(C). The *Equatorial-Tropical Flora* embraces the equatorial regions, and the tropical regions north and south;

* Community of *species* indicates a more recent connexion between two floras than community of *genera*, which are more generalized types, and therefore more remote in time. The figures here given show the following percentages of species:—

1. Peculiar to the islands, ...	72·4	per cent.
2. Common to Australia, ...	23·6	„
3. Common to South America, . .	11·9	„
4. Common to Europe, ...	6·2	„

and it may be conveniently divided either by temperatures or geographically. By temperatures—

1. The *Equatorial Zone.*
2. The *North and South Tropical Zones.*

Or as follows, geographically—

1. The *Asiatic Tropical Flora.*
2. The *African Tropical Flora.*
3. The *American Tropical Flora.*

The African tropical region contains Asiatic and American types, but it is sufficiently distinguished from both by its Palms, of which only from 2 to 10 per cent. are found common.

1. The *Equatorial* zone ranges to about 15° latitude on both sides of the equator, having a mean annual temperature of from 78° F. to 82° F. The characteristic plants of this zone include the following, among others :—

1. *Palmæ*, ...	Palms.
2. *Pandanaceæ*, . .	Screw Pines.
3. *Musaceæ*, ...	Bananas.
4. *Gramineæ*, . . .	Bamboos.
5. *Orchidaceæ*, . . .	Epiphytes.
6. *Malvaceæ*, . . .	Cotton, Baobab.
7. *Anonaceæ*, . . .	Custard Apple.
8. *Anacardiaceæ*, . .	Cashew nut, Mango.
9. *Artocarpeæ*, . . .	Bread Fruit.
10. *Guttiferæ*, . . .	Gamboge.
11. *Myrtaceæ*, . . .	Allspice, Guava.
12. *Cedrelaceæ*, . . .	Mahogany.

The whole *Equatorial* zone is characterized by the extreme luxuriance of the vegetation, caused by the great heat and abundant moisture; and, where water is wanting, the region is a desert. The trunks of the trees attain enormous dimensions, and are overgrown with orchids, lianas, aroids, and ferns, and the flowers possess most brilliant colours.

2. The *North and South Tropical* zones lie from 15° to 23° latitude north and south of the equator, and have a mean annual temperature ranging from 73° F. to 78° F.; the summer temperature being from 80° F. to 86° F., and the winter temperature about 60°.

Many of the plants of the equatorial zone are still found, with the following additions, among others—

1. *Filices*, ...	Tree ferns.
2. *Piperaceæ*, . . .	Pepper, Cubebs, Betel.
3. *Convolvulaceæ*, . .	Jalap, Scammony, Sweet Potato.

The forests of the tropical zones contain fewer Epiphytes and more underwood than the forests of the equatorial zone.

The Tertiary Northern Flora.—The northern and southern floras, in past times spreading from the North and South Poles, as centres, gradually migrated towards the equator as the earth cooled down, and they must in time have met and commingled in the equatorial and tropical regions.

In periods of heat-retrogression (such as the glacial), the plants migrated in the opposite direction, especially along the meridian chains; and in this way the special productions of the northern and southern hemispheres were sometimes carried into the wrong hemisphere, producing a mixture of forms, which has led some botanists to believe that the entire flora of the globe has had one origin only, instead of two origins from both poles, as already explained.

We know almost nothing of the Tertiary Flora of the southern hemisphere, while that of the northern has been recently carefully examined, and is now well known, chiefly through the labours of Professor Heer, of Zurich, who has removed from botanists the reproach that they had afforded to geologists but little assistance as compared with that given to them by zoologists.

A new science has been created by Heer's labours, and one that throws a bright light not only on the pedigree of the living flora of the globe, but also on the physical theory of the climates that prevailed over the temperate and arctic regions of the northern hemisphere during Tertiary periods.

I shall select a few examples to illustrate this novel branch of Geology and Physical Geography.

Comparison between the Present and the Miocene Climates of Grinnell Land.—The English Arctic Expedition, 1875–6, affords us an opportunity of contrasting the present and Miocene floras of one of the most northern lands yet reached by our explorations. An outline of the Miocene flora of this high latitude, 81° 44′ north, has been already given by me,* and I shall now endeavour to compare it with its present scanty flora.

The following is a summary of the present flora of

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* *Vide* pp. 85–87.

Grinnell Land. There were found altogether 59 species of plants, having the following relationships:—

Present Grinnell Land Flora, percentages common to.

1.	Grinnell Land, . .	100·0 per cent.
2.	Greenland, ...	96·6 „
3.	Arctic America, . .	96·6 „
4.	Europe, ...	76·3 „
5.	Arctic Asia, ...	76·3 „
6.	Alps, ...	55·9 „

The Miocene plants of Grinnell Land were discovered in Lignite beds, only two days before the expedition left to return home. The plants brought home contained 30 species, which are thus classified:—

Miocene Grinnell Land Flora.

1.	*Equisetaceæ*, ...	2
2.	*Coniferæ*, ...	11
3.	*Gramineæ*	3
4.	*Poplar*, ...	2
5.	*Birch*, ...	2
6.	*Hazel*, ...	2
7.	*Viburnum*, ...	1
8.	*Willow*, ...	1
9.	*Elm*, ...	1
10.	*Tilia*, ...	1
11.	*Sedge*, ...	1
12.	*Iris* (?), ...	1
13.	*Nymphæa*, ...	1
14.	*Doubtful*, ...	1
		30

Among the conifers, one of the most remarkable is the *Taxodium distichum*, which is closely related to *T. sempervirens*, or Swamp Cypress, still living wild in Virginia, and cultivated in Europe. Its usual northern limit in Virginia* and Kentucky is 40° N. Latitude. Its extreme northern limit is 43° Latitude, which corresponds to

July, ...	71°·2 F.
January, . . .	21°·0 ,,

The *Taxodium sempervirens*, under cultivation, thrives in Europe at the following stations, limiting it to the north :—

1. Dublin,†	July, ...	61°0· F.
,,	January, . . .	39°·0 F.
	Mean, . .	50° F.
2. Bern,	July, ...	62°·2 F.
,,	January, . . .	33°·9 F.
	Mean, . .	48°·0 F.
3. Berlin,	July, ...	63°·5 F.
,,	January, . . .	33°·1 F.
	Mean, . .	48°·3 F.

These four results, which agree fairly well together,

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* The climate of Northern Virginia is repeated in Europe in Southern Russia (Kiev).

† Although the *Taxodium sempervirens* flowers and fruits in the Trinity College Botanical Garden, it is doubtful if the seeds would grow there.

give for the northern limit of the swamp cypress :—

July, ...	64°·5 F.
January, ...	21°·0 „
Range, ...	43°·5 „

Let us compare this with the present temperatures* of Discovery Harbour (81° 44′ N. Lat.), where the Miocene beds were found.

Discovery Harbour.

July, ...	+ 37°·2 F.
Mean annual, ...	− 4°·2 „
January, ...	− 40°·6 „
Range, ...	77°·8 „

So far, therefore, as the evidence of the swamp cypress goes, it would appear that the summer temperature of Grinnell Land was more than 27° F. higher than at present.

The *Lime* (*Tilia Malmgreni*) found in the Miocene beds of Grinnell Land is very closely related to one of the American limes, whose northern limit is found, like that of *Taxodium*, at Lake Winnipeg, and it is somewhat more remotely related to European limes, whose northern limits are Drontheim (Norway) and St. Petersburg. From these data we have—

* "Voyage to the Polar Sea," by Capt. Sir G. S. Nares, R.N., K.C.B. Vol. ii. pp. 354, 355.

1. Lake Winnipeg—

July, ...	70°.0 F.
Annual, ...	40°·0 „
January, ...	10°·0 „

2. Drontheim,

July, ...	59°·3 F.
Annual, ...	42°·7 „
January, ...	26°·1 „

3. St. Petersburgh—

July, ...	63°·0 F.
Annual, ...	40°·0 „
January, ...	17°·0 „

The mean of these concurrent data gives us, for the northern limit of *Tilia*—

July, ...	64°·1 F.
Annual, ...	40°·9 „
January, ...	17°·7 „

Among the conifers found in Grinnell Land were the *Pinus abies*, Linn., and *Pinus Dicksoniana*, Hr., the latter closely related to the *Tsuga Canadensis*, still living in North America.

The northern limits of *Pinus abies* and its allies are as follow: 70° N. in America (*P. alba*), 68° 10′ N. in Europe, and 60° N. in Siberia (*P. obovata*). These data give us for temperature limits—

Pinus abies (*and allies*).

	America.	Europe.	Siberia.
July, . .	50°·0 F.	50°·6 F.	64°·5 F.
January, .	− 25°·0 „	− 22°·6 „	− 30°·0 „

The mean of these gives—

July, ...	55°·0 F.
January, . .	−25°·9 ,,

The hemlock spruce (*Tsuga Canadensis*) ranges from Hudson's Bay to Ohio, and a similar species ranges from Sitka to California. These data give us, for the northern limit—

	Hudson's Bay.	Sitka.	Mean.
July, . .	60°·0 F.	60°·2 F.	60°·1 F.
January, .	0°·0 ,,	14°·0 ,,	7°·0 ,,

The American poplars (*Populus*) and elms (*Ulmus*) range as far north as 54° latitude on the Saskatchewan river, indicating the following climate for their northern limit—

July, ...	66°·0 F.
January, . . .	8°·0 ,,

The Guelder rose (*Viburnum*) and white water-lily (*Nymphæa*) spread all over Europe, with the exception of Lapland, indicating the climate—

July, ...	55°·8 F.
January, . . .	15°·8 ,,

The willow (*Salix*), birch (*Betula*), and *Iris* range all over Europe, including Lapland, and thus possess the power of bearing a climate as severe as the following :—

July, ...	49°·0 F.
January, . . .	11°·5 ,,

The hazel (*Corylus*) has 63° latitude for its northern limit in Sweden, which indicates the climate—

July, ...	55°·8 F.
January, . . .	28°·5 „

Let us now collect together the records of these plant self-registering thermometers of the Miocene period in Grinnell Land, and endeavour to read their evidence. In considering the influence of temperature upon plant life, there are two important points to be kept in view :—

1. The July temperature (summer), necessary to enable the plant to flower and fruit perfectly.

2. The January temperature (winter), which the plant is capable of enduring with safety.

If we classify the Flora of Miocene times in Grinnell Land, in this twofold point of view, we obtain the following results as to the climate of the place and time :—*

Northern limit.

1. *Taxodium,*	July, ...	64°·5 F.
	January, ...	21°·0 „
	Range, ...	43°·5 „
2. *Populus,*	July, ...	66°·0 F.,
and *Ulmus,*	January, ...	8°·0 „
	Range, ...	58°·0 „

* I assume for the summer temperature the *mean* of the data given; and for the winter temperature the *minimum*, because the plant lives through it.

3. *Tsuga*,	July, ...	60°·1 F.	
	January, ...	0°·0 ,,	
	Range, ...	60°·1 ,,	
4. *Tilia*,	July, ...	64°·1 F.	
	January, ...	10°·0 ,,	
	Range, ...	54°·1 ,,	
5. *Pinus abies*,	July, ...	55°·0 F.	
	January, ...	–30°·0 ,,	
	Range, ...	85°·0 ,,	
6. *Viburnum*,	July, ...	55°·8 F.,	
and *Nymphæa*,	January, ...	15°·8 ,,	
	Range, ...	40°·0 ,,	
7. *Salix*,	July, ...	49°·0 F.	
Betula and *Iris*,	January, ...	11°·5 ,,	
	Range, ...	37°·5 ,,	
8. *Corylus*,	July, ...	55°·8 F.	
	January, ...	28°·5 ,,	

The foregoing trees and plants may be classified under three groups, with respect to the summer temperature that limits their progress polewards.

First Group.

1. *Taxodium*, 2. *Populus*, 3. *Ulmus*, 4. *Tsuga*, 5. *Tilia*,	These trees cannot migrate farther north than places whose July temperature is 63°·7 F.

Second Group.

6. *Pinus abies* (and Allies), 7. *Viburnum*, 8. *Nymphæa*, 9. *Corylus*,	This group of trees, shrubs, and herbs, cannot migrate farther north than places whose July temperature is 55°·5 F.

Third Group.

10. *Salix*, 11. *Betula*, 12. *Iris*,	These trees and herbs can migrate as far north as places which possess a July temperature of 49°·0 F.

So far as summer temperature is concerned, the second and third group can live where the first group attains its northern limit.

My first conclusion, therefore, as to the climate of Grinnell Land in Miocene times is, that it must have had a *July temperature higher than* 63°·7 F.

If we now examine the January temperatures, we find that, while *Taxodium** will not bear a lower winter

* It is plainly the January temperature that limits the northern migration of the Swamp Cypress to 43° N. Lat., and not the July temperature; for the latter is still 60° F. at 50° Lat., while the former goes down to *zero*.

temperature than 21° F., the other eleven trees and plants can endure much lower January limits—the most remarkable of all, in this respect, being *Pinus abies* and its allies.

We therefore conclude that the *January temperature* of Grinnell Land in Miocene times was *not lower than* 21° F. Hence we find, for Grinnell Land climate—

	Miocene period (Lower limit).	Present time.	Difference.
July, . . .	63°·7 F.	37°·2 F.	26°·5 F.
January, . .	21°·0 „	- 40°·6 „	61°·6 „
Range, . .	42°·7 „	77°·8 „	35°·1 „

I find, by using Ferrel's Tables, that the Miocene climate of Grinnell Land corresponds very closely with 46° N. Lat., 60° W. Long., or with the climate of *Cape Breton Island*, in the south of the Gulf of St. Lawrence.

In Europe, I find the Miocene climate of Grinnell Land to correspond very closely with Lat. 56° N., Long. 24° E., or with the climate of *Riga Bay*, on the south shore of the Baltic sea.

There are no other present climates in the northern hemisphere corresponding with the Miocene climate of Grinnell Land; and there is no place whatever in the southern hemisphere possessing that climate.

It is not a little curious that Grinnell Land is situated on the same meridian as Cape Breton Island, but lies 2520 miles to the north of it (36°)*.

* No sane man can believe that the North Pole has been displaced through upwards of 2000 miles!

Comparison between the Present and Miocene Climates of Spitzbergen.—Next to Grinnell Land, Spitzbergen is the place nearest the North Pole, where an abundant Miocene Flora has been found.

The present climate of Spitzbergen (78° N. Lat.) is as follows:—

July, ...	37°·2 F.
Annual, ...	16°·5 ,, *
January, ...	– 4°·2 ,,
Range, . . .	41°·4 ,,

The Miocene Tertiary Flora of Spitzbergen has yielded 132 species of plants; including 39 trees, 20 shrubs, and 38 herbaceous plants.

The present Flora of Spitzbergen has yielded 110 species, of which 3 only have woody stems.

Among the trees of the Miocene period in Spitzbergen, the following may be used as natural thermometers to estimate the temperature of the Miocene climate: the Beeches (*Fagus*), the Planes (*Platanus*), the Limes (*Tilia*), the Swamp Cypresses (*Taxodium*), the Big Trees (*Sequoia*), the Incense Cedars (*Libocedrus*), the Walnut Trees (*Juglans*).

The species of Beech (*Fagus*) nearest to those of the Miocene Beeches of Spitzbergen have for their northern limit in Scotland 57° N. Lat., in Norway 60° N. Lat., and in Sweden 57° N. Lat. In America, *Fagus ferruginea,* which is somewhat more remotely related to the Spitzbergen Miocene Beeches, attains its northern

* The Gulf Stream is the cause of the high mean annual temperature of Spitzbergen, as compared with that of Grinnell Land.

limit at 50° 30′ N. Lat. at Lake Winnipeg. These data give us the following temperatures:—

July temperature.

Scotland, . . .	61°·2 F.
Norway, ...	63°·0 ,,
Sweden, ...	62°·4 ,,
Winnipeg, . . .	70°·0 ,,
Mean, . . .	64°·1 F.

Mean Annual temperature.

Scotland, . . .	47°·1 F.
Norway, . . .	45°·0 ,,
Sweden, ...	47°·6 ,,
Winnipeg, . . .	40°·0 ,,
Mean, . . .	44°·9 F.

January temperature.

Scotland, . . .	33°·0 F.
Norway, ...	27°·0 ,,
Sweden, ...	32°·8 ,,
Winnipeg, . . .	10°·0 ,,
Mean, . . .	25°·7 F.

Species of American Plane tree (*Platanus*) grow wild in 50° N. Lat., near Lake Superior; and the cultivated European species has its northern boundary at Koenigsberg, 55° N. Lat. These localities give the following temperatures for the northern limit.

Lake Superior:—

July, ...	68° F.
Annual, ...	36° ,,
January, ...	4° ,,

Koenigsberg:—

July, ...	64° F.
Annual, ...	45° ,,
January, ...	26° ,,

The mean of these is, for *Platanus*:—

July, ...	66°·0 F.
Annual, ...	40°·5 ,,
January, ...	15°·0 ,,

The July and mean annual temperatures corresponding with the northern limits of the Limes and Swamp Cypresses, have already been discussed in dealing with the Miocene climate of Grinnell Land.

The Big Trees* (*Sequoia*) of Spitzbergen give us important information as to climate, for they fix not only

* Professor Asa Gray has given the following interesting account of the two surviving species of "big trees," *Sequoia sempervirens* and *Sequoia gigantea*, and of other rare surviving forms of conifers, in his Presidential Address to the American Association for the Advancement of Science (Iowa, 1872):—

"To gratify a natural interest, and to gain some title for addressing a body of practical naturalists and explorers, I have made a pilgrimage across the continent; I have sought and viewed in their native haunts many a plant and flower which, for me, had long bloomed unseen, or only in the hortus siccus. I have been able to see for myself what species and what a summer and annual temperature, but they determine a limit to the *winter cold* possible for these trees.

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forms constitute the main features of the vegetation of each successive region, and record—as the vegetation unerringly does—the permanent characteristics of its climate. Although no account and no photographic representation of either species of the far-famed Sequoia trees gives any adequate impression of their singular majesty—still less of their beauty—yet my interest in them did not culminate merely nor mainly in consideration of their size or age. Other trees in other parts of the world may claim to be older. Certain Australian gum trees (Eucalypti) are said to be taller. Some, we are told, rise so high that they might even cast a flicker of shadow upon the summit of the pyramid of Cheops. Yet the oldest of them doubtless grew from seed which was shed long after the names of the pyramid builders had been forgotten. So far as we can judge from the actual counting of the layers of several trees, no Sequoia now alive can much over-date the Christian era.

"One notable thing about these Sequoia trees is their isolation. Most of the trees associated with them are of peculiar species, and some of them nearly local. Yet every Pine, Fir, and Cypress in California is in some sort familiar, because it has near relations in other parts of the world; but the Redwoods have none. The Redwood—including in that name the two species of 'big trees'—belongs to the general Cypress family, but is *sui generis*. Thus isolated systematically, and extremely isolated geographically, and so wonderful in size and port, they more than other trees suggest questions. Were they created thus local and lonely, denizens of California only; one in limited numbers in a few choice spots on the Sierra Nevada, the other only along the coast-range from the Bay of Monterey, to the frontiers of Oregon? Are they veritable Melchisedeks, without pedigree or early relationship, and possibly fated to be without descent? Or are they now coming upon the stage (or, rather, were they coming but for man's interference), to play a part in the future? Or are they remnants—sole and scanty survivors of a race that has played a grander part in the past, but is now verging to extinction? Have they had a career, and can that career be ascertained or surmised, so that we may at least guess whence they came, and how, and when? Time was, and not long ago, when such questions as these were regarded as useless and vain—when students of natural history, unmindful of what the name denotes, were content with a knowledge of things as they now are, but gave little heed as to how they came to be so. Now, such questions are

The living species (*Sequoia sempervirens*) nearest to that of the Spitzbergen Miocene beds forms large forests

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held to be legitimate, and perhaps not wholly unanswerable. It cannot now be said that these trees inhabit their present restricted areas simply because they are there placed in the climate and soil of all the world most congenial to them. These must indeed be congenial or they would not survive. But when we see how Australian Eucalyptus trees thrive upon the Californian coast, and how these very Redwoods flourish upon another continent, we must abandon the notion of any primordial and absolute adaptation of plants to their habitat, which may stand in lieu of explanation, and so preclude our inquiring any further. The harmony of nature and its admirable perfection need not be regarded as inflexible and changeless. Nor need Nature be likened to a statue, or a cast in rigid bronze, but rather to an organism, with play and adaptability of parts, and life and even soul informing the whole. Under the former view, Nature would be 'The faultless monster the world ne'er saw,' but inscrutable as the Sphinx, whom it were vain, or worse, to question of the whence and whither. Under the other, the perfection of Nature, if relative, is multifarious and ever renewed; and much that is enigmatical now may find explanation in some record of the past.

"That the two species of Redwood we are contemplating originated as they are, and for the part they are now playing, is, to say the least, not a scientific supposition, nor in any sense a probable one. Nor is it more likely that they are destined to play a conspicuous part in the future, or that they would have done so even if the Indian's fires and the white man's axe had spared them. The Redwood of the coast, *Sequoia sempervirens*, had the stronger hold upon existence, forming, as it did, large forests throughout a narrow belt about 300 miles in length, and being so tenacious of life that every large stump sprouts into a copse. But it does not pass the Bay of Monterey, nor cross the line of Oregon, although so grandly developed not far below it. The more remarkable *Sequoia gigantea* (Wellingtonia) of the Sierra exists in numbers so limited that the separate groves may be reckoned on the fingers, and the trees of most of them have been counted, except near their southern limit, where they are said to be more copious. A species limited to individuals holds its existence by a precarious tenure; and this has a foothold only in a few sheltered spots, of a happy mean in temperature and locally favoured with moisture in summer. Even then, for some reason or other, the Pines with which they are associated (*Pinus Lambertiana* and *P. ponderosa*), the Firs (*Abies grandis* and in California, and spreads over Mexico as far as 42° N. Lat. In British Columbia the tree ceases to exist.

A. amabilis), and even the Incense Cedar (*Libocedrus decurrens*), possess a great advantage, and though they strive in vain to emulate their size, wholly overpower the Sequoia in numbers. 'To him that hath shall be given.' The force of numbers eventually wins. At least, in the commonly visited groves, *Sequoia gigantea* is invested in its last stronghold, can neither advance into more exposed positions above, nor fall back into drier and barer ground below, nor hold its own in the long run where it is, under present conditions; and a little further drying of the climate, which must once have been much moister than now, would precipitate its doom. Whatever the individual longevity, certain, if not speedy, is the decline of a race in which a higher death-rate afflicts the young. Seedlings of the big trees occur not rarely, indeed, but in a small proportion to those of associated trees; and small indeed is the chance that any of these will attain to 'the days of the years of their fathers.' 'Few and evil' are the days of all the forest likely to be, while man, both barbarian and civilised, torments them with fires, fatal at once to seedlings, and at length to the aged also. The forests of California, proud as the State may be of them, are already too scanty and insufficient for her uses. Two lines, such as may be drawn with one sweep of a small brush over the map, would cover them all.

"The Coast Redwood—the most important tree in California—although a million times more numerous than its relative of the Sierra, is too good to live long. Such is its value for lumber, and its accessibility, that judging the future by the past, it is not likely, in its primeval growth, to out-last its rarer fellow species. Happily man preserves and disseminates as well as destroys. The species will probably be indefinitely preserved to science, and for ornamental and other uses in its own and other lands, and the more remarkable individuals are likely to be sedulously cared for, all the more so as they become scarce. One third question remains to be answered: Have these famous Sequoias played in former times and upon a larger stage a more imposing part, of which the present is but the epilogue? We cannot gaze high up the huge and venerable trunks without wishing that these patriarchs of the grove were able, like the long-lived antediluvians of Scripture, to hand down to us, through a few generations, the traditions of centuries, and so tell us somewhat of the history of their race. Fifteen hundred annual layers have been counted or satisfactorily made out upon one or two fallen trunks. It is probable that close to the heart of some of the living trees may be found the circle that records the year of our

When cultivated in Europe, its northern limit corresponds with the climate of Dublin, where, however, it does not

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Saviour's nativity. A few generations of such trees might carry the history a long way back. But the ground they stand upon, and the marks of very recent geological change and vicissitude in the region around, testify that not very many such generations can have flourished just there, at least in an unbroken series. When their site was covered by glaciers these Sequoias must have occupied other stations, if, as there is reason to believe, they then existed in the land. I have said the Redwoods have no near relatives in the country of their abode, and none of their genus anywhere else. Perhaps something may be learned of their genealogy by inquiring of such relatives as they have. There are only two of any particular nearness of kin, and they are far away. One is the bald Cypress, our Southern Cypress, *Taxodium distichum*, inhabiting swamps of the Atlantic coast from Maryland to Texas, thence extending into Mexico. It is well known as one of the largest trees of our Atlantic forest district; and although it never (except perhaps in Mexico and in rare instances) attains the portliness of its western relatives, yet it may equal them in longevity. The other relative is Glyptostrobus, a sort of modified Taxodium, being about as much like our Bald Cypress as one species of Redwood is like the other.

"Now species of the same type, especially when few and the type peculiar, are in a general way associated geographically, *i.e.* inhabit the same country or (in a larger sense) the same region. Where it is not so, where near relatives are separated, there is usually something to be explained. Here is an instance. These four trees, sole representatives of their tribe, dwell almost in three separate quarters of the world; the two Redwoods in California, the Bald Cypress in Atlantic North America, its near relative, Glyptostrobus, in China. It was not always so. In the tertiary period, the geological botanists assure us, our own Taxodium or Bald Cypress, and a Glyptostrobus exceedingly like the present Chinese tree, and more than one Sequoia, co-existed in a fourth quarter of the globe, viz., in Europe. This brings up the question: Is it possible to bridge over these four wide intervals of space (amounting to three-quarters of the earth's circumference), and the much vaster interval of time, so as to bring these extraordinarily separated relatives into connection? The evidence which may be brought to bear upon this question is various and widely scattered. Some interesting facts may come out by comparing generally the botany of the three remote regions, each of which is the sole fruit perfectly. But it is remarkable, that although the tree flourishes at Paris, its fruit is destroyed by the *winter cold* of that locality.

These data give us the following temperatures:—

1. British Columbia (beyond limit in winter)—

July, ...	68°·0 F.
Annual, ...	49°·0 „
January, . . .	30°·0 „

2. Dublin (beyond limit in summer)—

July, ...	61°·0 F.
Annual, ...	50°·0 „
January, . . .	39°·0 „

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home of one of these three genera, *i.e.* Sequoia in California, Taxodium in the Atlantic United States, and Glyptostrobus in China, which compose the whole of the peculiar tribe I am speaking of.

"Note, then, first, that there is another set of three or four peculiar trees in the case of the Yew family, which has just the same peculiar distribution, and which therefore may have the same explanation, whatever that explanation be. The genus Torreya, which commemorates our botanical Nestor, and a former president of this association, Dr. Torrey, was founded upon a tree rather lately discovered (that is, about thirty-five years ago) in Northern Florida. It is a noble Yew-like tree, and very local, being known only for a few miles along the shores of a single river. It seems as if it had somehow been crowded down out of the Alleghanies into its present limited southern quarters, for in cultivation it evinces a northern hardiness. Now, another species of Torreya is a characteristic tree of Japan, and the same, or one very like it indeed, inhabiting the Himalayas, belongs therefore to the Eastern Asiatic temperate region, of which China is a part, and Japan, as we shall see, the portion most interesting to us. There is only one more species of Torreya, and that is a companion of the Redwoods in California. It is the tree locally known under the name of the Californian Nutmeg. In this case the three are near brethren, species of the same genus, known nowhere else than in these habitats. Moreover, the Torreya of Florida has growing with it a Yew tree, and the trees of that grove are the only Yew trees of Eastern America,

3. Paris (beyond limit in winter)—

July, ...	65°·2 F.
Annual, ...	51°·1 „
January, . . .	37°·0 „

Taking into consideration the facts that the *Sequoia* ceases to exist in British Columbia, and often has its fruit destroyed by the winters of Paris, we may regard the following as the *limiting* climate of the *Sequoia*:—

July,*	64°·7 F.*	
January, . . .	39°·0 „	(Dublin).
Range, ...	25°·7 „	

for the Yew of our northern woods is a decumbent shrub. The only other Yew trees in America grow with the Redwoods and the other Torreya in California, and more plentifully further north, in Oregon. A Yew tree equally accompanies the Torreya of Japan and the Himalayas, and this is apparently the same as the common Yew of Europe.

"So we have three groups of trees of the great coniferous order, which agree in this peculiar geographical distribution—the Redwoods and their relatives, which differ widely enough to be termed a different genus in each region; the Torreyas, more nearly akin, merely a different species in each region; the Yews, perhaps all the same species, perhaps not quite that, for opinions differ, and can hardly be brought to any decisive test. The Yews of the Old World, from Japan to Western Europe, are considered the same; the very local one in Florida is slightly different; that of California and Oregon differs a very little more; but all of them are within the limits of variation of many a species. However that may be, it appears to me that these several instances all raise the same question, only with a different degree of emphasis, and, if to be explained at all, will have the same kind of explanation."—*The Garden*, vol. ii. pp. 337-8.

* Mr. F. W. Burbidge (Trinity College Botanical Gardens) informs me that the *Sequoia gigantea* (Wellingtonia) has fruited freely, and that healthy offspring from its seed has been produced at the seat of Lady Rolle, Bicton, Devonshire. This fact fixes the limiting July temperature at 64°.0 F. The January temperature of South Devon is 40° F.

The Incense Cedar (*Libocedrus*).—The *Libocedrus decurrens* of California extends into Oregon as far north as 44° Lat., forming large trees; and, under cultivation, has fruited perfectly in Warwickshire.* This corresponds with a climate as follows:—

	Oregon.	Warwickshire.	Mean.
July, . .	65°·0 F.	63°·4 F.	64°·2 F.
January, .	41°·2 „	37°·2 „	39°·2 „

Although the Walnut (*Juglans*) grows well in Dublin, the summer temperature is scarcely sufficient to ripen its fruit fully. The tree seems to flourish best on the slopes of the Italian side of the Alps, and it ranges as far east as Warsaw. From these data we find—

	Warsaw.	Dublin.	Italian Alps.	Mean.
July, . .	64° F.	61° F.	68°·3 F.	64°·4 F.
January,	26° „	39° „	37°·6 „	34°·2 „

If we now discuss the probable Miocene climate of Spitzbergen by the light of the foregoing facts, we shall find its trees pointing to two limiting types of climate quite distinct from each other. The first of these is a warmer *insular* type, viz.:—

	July.	January.	Range.
1. *Sequoia*, . .	64°·7 F.	39°·0 F.	25°·7 F.
2. *Libocedrus*, .	64°·2 „	39°·2 „	25°·0 „
Mean, .	**64°·4 F.**	**39°·1 F.**	**25°·3 F.**

If we determine (with the aid of Ferrel's Tables) the

* In the grounds of Combe Abbey, near Coventry.

existing places that enjoy a July temperature of 65° F. and a range of 25° F., we find—

In the Southern Hemisphere,	*No locality.*
In the Northern Hemisphere,	(*a*) *Straits of Dover.*
	(*b*) *Vancouver's Island.*

It follows, conclusively, from the presence of this group of trees, that during the Miocene period Spitzbergen enjoyed an *insular* climate like that of the British Islands and Vancouver's Island at the present day.

The second type of climate is indicated by the presence of a group of trees, requiring about the same July temperature as the former group, but capable of undergoing a more severe winter. These trees are:—

	July.	January.*	Range.
1. *Taxodium*, .	65°·7 F.	30°·0 F. North Virginia.	35°·7 F.
2. *Tilia*, . . .	64°·1 „	10°·0 „ Winnipeg.	54°·1 „
3. *Fagus*, . . .	64°·1 „	10°·0 „ Winnipeg.	54°·1 „
4. *Juglans*, . .	64°·4 „	26°·0 „ Warsaw.	38°·4 „
5. *Platanus*, . .	66°·0 „	4°·0 „ Lake Superior.	42°·0 „
Mean, . .	64°·9 F.		

It is plain, on inspection of these temperatures, especially the summer temperature necessary for flowering and fruiting, that all these trees, although capable of enduring a continental climate, could thrive and

* I use here the lowest January temperatures endurable by each tree.

flourish luxuriantly in the insular Miocene climate of Spitzbergen, and so far at least as January cold is concerned, if land communication permitted, might spread northwards as far as the Pole itself.

I have already fixed a lower limit to the Miocene climate of Grinnell Land by means of the Swamp Cypress, corresponding to the climate of the Gulf of St. Lawrence or that of the Bay of Riga, viz. :—

*Grinnell Land (Miocene).**

July temperature, ...	63°·7 F.
Annual range, ...	42°·7 „

This is a decided continental climate when compared with the corresponding climate of Spitzbergen, viz. :—

Spitzbergen (Miocene).†

July temperature, ...	64°·4 F.
Annual range, ...	25°·3 „

The present climates are :—

Present Climates.

	Grinnell Land.	Spitzbergen.
July, ...	37°·2 F.	37°·2 F.
Annual range, ...	77°·8 „	41°·4 „

It follows, that in the Miocene time, as at present, causes were at work which made the summer temperatures of Grinnell Land and Spitzbergen sensibly equal; and that other causes were at work at both periods which

* *Vide* p. 322. † *Vide* p. 332.

give a small annual range (*insular*) to Spitzbergen, and a large annual range (*continental*) to Grinnell Land.

I draw, briefly, the following conclusions from the facts:—

1. The Miocene July temperature of both places was 28° F. higher than at present.

2. The Gulf Stream, which is *now* the cause of the difference between the climates of Spitzbergen and Grinnell Land, occupied in *Miocene times* the same position as at present, and performed the same friendly function to Spitzbergen.

3. The Atlantic Ocean occupied its present position; and the *impossible* bridge between Greenland and Europe did not exist.

These facts will be more clearly brought out after we shall have considered the Miocene climate of Disco.

The Miocene Flora of Disco.—The island of Disco, Lat. 70° N. on the west coast of Greenland, has furnished the earliest and best known Flora of the Arctic Miocene period, and a comparison of it with the preceding Floras of Grinnell Land, 82° N., and of Spitzbergen, 78° N., will be instructive.

The following trees, which occur abundantly in the lignite beds of Disco, give valuable information as to the former climate: viz., the Big Trees (*Sequoia*), the Water-pines (*Glyptostrobus*), the Japanese Maiden-hair Pines (*Salisburia*), the Evergreen Oaks, the allies of the Elm trees (*Planera*), the Hornbeam (*Carpinus*), the Date-plum (*Diospyros*), the Vines (*Vitis*), the Jew-thorn (*Paliurus*), the Magnolia and Walnut (*Juglans*), and the Cherry (*Prunus*).

The climate temperatures of the northern limit of *Sequoia* have been already given. The Water-pines

(*Glyptostrobus**) are found wild in China as far north as 36° Lat., and flourish in Japan at 40° Lat., and thrive under cultivation at Vienna. These data give us the following temperatures.

China (36° N. Lat.) :—

July, ...	79°·6 F.
Annual, ...	53°·8 ,,
January, . . .	28°·0 ,,

Japan (40° N. Lat.) :—

July, ...	70°·0 F.
Annual, ...	50°·0 ,,
January, . . .	30°·0 ,,

Vienna :—

July, ...	67°·9 F.
Annual, ...	52°·2 ,,
January,. . . .	31°·6 ,,

The mean of these gives, for the northern limit of the *Glyptostrobus* :—

July, ...	72°·5 F.
Annual, ...	52°·0 ,,
January,. . . .	29°·9 ,,

The Japanese Maiden-hair Pines (*Salisburia*)† are found in Japan at 40° N. Lat., but have never fruited in

* This (*G. heterophyllus*) is one of the rarest of cultivated conifers, and has not been known to fruit in England.

† The "Ginkgo" tree of Japan.

England.* The northern limits of the tree, producing perfect fruit, are Venice, Vienna, and 40° N. in Kentucky. These data give for the northern limit:—

Salisburia.

	Japan.	Venice.	Vienna.	Mean.
July, .	70°·0 F.	70°·9 F.	67°·9 F.	**71°·2 F.**
Annual,	50°·0 „	55°·0 „	52°·2 „	**52°·4 „**
January,	30°·0 „	39°·0 „	31°·6 „	**32°·6 „**

Among the numerous Oaks (*Quercus*) found in the Miocene beds at Disco there are three evergreen Oaks, two of which are closely related to Mexican evergreen Oaks now living. In Europe, the climate of Lausanne forms the northern boundary of the hardiest evergreen Oak. Hence, we find for the probable limiting climate of the evergreen Oaks:—

	North Mexico.	Lausanne.
July, ...	70°·0 F.	65°·7 F.
Annual, . . .	55°·3 „	49°·0 „
January,. .	40°·6 „	30°·2 „

This gives for the mean climate:—

July, ...	**67°·8 F.**
Annual, ...	**52°·1 „**
January, ...	**35°·4 „**

Among the allies of the Elm trees in the Miocene Flora of Disco, the chief is *Planera Ungeri*, which comes

* This may possibly be owing to the absence of the male tree from the locality, for the *Salisburia* is diœcious.

extremely close to the living European species, *Planera Richardi*, which enjoys a very wide range of growth, extending from Crete and the Caucasus on the south and east, as far as Lausanne and Dublin on the north and west. Its northern limit of climate would probably be :—

	Lausanne.	Dublin.	Mean.
July, . .	65°·7 F.	60°·0 F.	**62°·8** F.
Annual, .	49°·0 „	50°·0 „	**49°·5** „
January, .	30°·2 „	40°·0 „	**35°·1** „

The Hornbeam (*Carpinus*) still grows in South Sweden and in the south-west corner of Courland. This corresponds to a climate of—

July, ...	63°·2 F.
Annual, ...	48°·7 „
January, . . .	34°·2 „

The European Date-Plum (*Diospyrós*) fruits well at Heidelberg, but not in Dublin. Hence, its northern limit will be :—

	Heidelberg.
July, ...	72°·5 F.
Annual, ...	52°·0 „
January, . . .	31°·5 „

The two Miocene Vines (*Vitis*) of Disco resemble closely two Vines now living in North America, the northern limits of which are Lake Winnipeg and the Ohio river in Western Virginia. These limits give us :—

	Winnipeg.	W. Virginia.	Mean.
July, . .	70°·0 F.	76°·0 F.	**73°·0** F.
Annual, .	40°·0 „	53°·0 „	**46°·5** „
January, .	10°·0 „	30°·0 „	**20°·0** „

The Jew-thorn (*Paliurus*) reaches its northern limit at Zurich, which indicates a climate—

	Zurich.
July, ...	65°·7 F.
January, ...	27°·5 „

The evergreen *Magnolia grandiflora* flourishes in the open air at Lausanne, but cannot endure the January climate of Zurich. This fact fixes its climate at

July, ...	65°·7 F.
January, ...	30°·2 „

The Cherry trees found in the Miocene beds of Disco are nearly related to *Prunus Lusitanica* and *P. lauro-cerasus.*

These are killed by the January temperature of Zurich, like *Magnolia grandiflora.*

The Walnut (*Juglans*) has been already discussed, and gives—

July, ...	64°·4 F.
January, ...	26°·0 „

The climates indicated by the foregoing twelve trees and shrubs may be thus classified:—

1. The *Glyptostrobus*, *Salisburia*, *Diospyros*, and *Vitis* indicate a higher July temperature than the others, with a power of enduring a January temperature ranging from 10° F. to 31°·5 F.

		Mean.
First Group,	July, ...	72°·3 F.
	January, . . .	25°·3 „

2. The *Sequoia*, *Quercus*, *Planera*, *Carpinus*, *Paliurus*, *Magnolia*, *Prunus*, and *Juglans* indicate a July temperature lower than the first group, and they could all endure as severe a January temperature as the former group, with the exception of *Sequoia*, which cannot bear a January temperature lower than 39° F. Omitting the *Sequoia*, we find—

		Mean.
Second Group,	July, ...	64°·5 F.
	January, . . .	29°·7 ,,

3. The *Sequoia*—

		Mean.
Third Group,	July, ...	64°·7 F.
	January, . . .	39° 0 ,,

The July temperature therefore of Disco island, in Miocene times, is determined by the first group, and the winter temperature by the third group, and was as follows :—

Miocene Climate of Disco.

July, ...	72°·3 F.
January, . . .	39°·0 ,,
Range, ...	33°·3 ,,

Again using Ferrel's Tables, I find this climate at present at the intersection of the parallel 40° N. with the meridian 60° W. This point is south of the Gulf of St. Lawrence, and 430 miles S.E. of Halifax, in Nova Scotia, and is nearly on the meridian of Disco. To effect this change of climate by a change in the position of the pole would require a transference of 30° Lat., or 2100 miles; a result very like that found from our discussion of the Miocene Flora of Grinnell Land.

Of the present climates of the Old World, that of *Belgrade*, on the Danube, corresponds closely with the Miocene climate of Disco.

Influence of the Gulf Stream upon the Present and Miocene Climate of Spitzbergen.—Grinnell Land, Disco, and Cape Farewell lie upon nearly the same meridian, and are entirely outside the influence of the Gulf Stream. Their present climates are as follow:—

	Lat.	July.	January.	Annual.
Grinnell Land,	81°·44	37°·2 F.	- 40°·6 F.	- 1°·7 F.
Disco, . . .	70°·00	44°·1 „	- 4°·9 „	19°·6 „
Cape Farewell,	60°·00	46°·4 „	22°·1 „	34°·2 „

If we plot (to scale) the latitudes and mean annual temperatures, we determine three points, through which a circle is to be described, which will represent (as nearly as the data allow) the law of variation of mean temperature with latitude, on this meridian, and between the limits. We can calculate, by this construction, the mean temperature, on this meridian, of the latitude of Spitzbergen, 78° N., and it turns out to be 5°·0 F.

The actual climate of Spitzbergen is the following:—

	Lat.	July.	January.	Annual.
Spitzbergen, . .	78°	37°·2 F.	- 4°·2 F.	16°·5 F.

Spitzbergen, therefore, has a mean annual temperature of 16°·5 F., instead of 5°·0 F., which would be its condition, if placed on the meridian of Grinnell Land and Disco. Hence I conclude that

The effect of the Gulf Stream upon the climate of Spitzbergen, at present, is to raise its mean annual temperature through 11°·5 F.

Let us now consider the Miocene climates of Grinnell Land, Disco, and Spitzbergen, which we have determined to be as follows:—

	Lat.	July.	January.	Annual.
Grinnell Land, .	81° 44′	63°·7 F.	21°·0 F.	42°·3 F.
Disco, ...	70° 00′	72°·3 „	39°·0 „	55°·6 „
Spitzbergen, . .	78° 00′	64°·4 „	39°·2 „	51°·8 „

If we now plot (to scale), as before, the mean annual temperatures and latitudes of Grinnell Land and Disco, we shall find two points, the line joining which will represent (as nearly as the data allow) the relation between mean annual temperature and latitude, in Miocene times, on the meridian of Grinnell Land and Disco.

From this construction, we find, for the mean annual temperature of 78° N. Lat., in Miocene times, 47°·0 F.

Hence, we finally obtain:—

Actual Miocene annual temperature of Spitzbergen, ...	51°·8 F.
Calculated annual temperature of Spitzbergen, if transferred to the meridian of Grinnell Land and Disco, ...	47°·0 „
Difference, ...	4°·8 F.

Or, in other words, the North Atlantic Gulf Stream, in Miocene times, raised the mean annual temperature of Spitzbergen through 4°·8 F.

We can obtain from the foregoing some interesting information as to the relative amounts of heat supplied to the earth at Spitzbergen, in Miocene times, and at present, from all sources.

Let E, S, denote the Earth-heat and Sun-heat, at present supplied to the earth at the latitude of Spitzbergen ; and let θ, θ' be the mean temperatures of the Spitzbergen latitude, with and without the Gulf Stream influence.

We now have, approximately,* if G denote the Gulf Stream heat supplied, and a denote the control temperature of the *Inclosure*, composed of the atmosphere and Star-heat, which regulates the radiation of heat from the air next the surface of the earth :—

$$E + S + G = k\,(\theta + a)\,;$$

$$E + S = k\,(\theta' + a)\,;$$

$$1 + \frac{G}{E + S} = \frac{16{\cdot}5 + a}{5{\cdot}0 + a}. \qquad (1)$$

Also, using dotted letters to denote the similar quantities in Miocene times, we have—

$$E' + S' + G' = k'\,(\theta + a')\,;$$

$$E' + S' = k'\,(\theta' + a')\,;$$

$$1 + \frac{G'}{E' + S'} = \frac{(51{\cdot}8 + a')}{(47{\cdot}0 + a')}. \qquad (2)$$

If we assume $a = 160{\cdot}5$*, we find from (1)—

$$\frac{G}{E + S} = 0{\cdot}0695.$$

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* *Vide* Note, p. 346.

And, if $a = a'$, or the control temperature were the same in Miocene times as now, equation (2) gives us—

$$\frac{G'}{E' + S'} = 0{\cdot}0231.$$

From these results it appears that the Gulf Stream of Miocene times might have borne a less proportion to the Sun- and Earth-heat than at present; but the actual Gulf Stream heat in Miocene times might have been greater than now, because the total of Earth- and Sun-heat was greater.

The following Table, taken partly from Prof. O. Heer's results, and calculated partly by myself, shows the profound change in climate that has taken place in the northern hemisphere in the intervals from Miocene times to the present:—

	Lat.	Sea level. Present.	Miocene.	Difference.
1. Switzerland,* . .	47°·00′	53°·6 F.	69°·8 F.	Minus. 16°·2 F.
2. Dantzig,* . . .	54°·21	45°·7 ,,	62°·6 ,,	16°·9 ,,
3. Iceland,* . . .	65°·30	35°·6 ,,	48°·2 ,,	12°·6 ,,
4. Mackenzie River,*	65°·00	19°·4 ,,	48°·2 ,,	28°·8 ,,
5. Disco, ...	70°·00	19°·6 ,,	55°·6 ,,	36°·0 ,,
6. Spitzbergen, . .	78°·00	16°·5 ,,	51°·8 ,,	35°·3 ,,
7. Grinnell Land, .	81°·44	− 1°·7 ,,	42°·3 ,,	44°·0 ,,

* Heer, *Flora fossilis Arctica*: Zurich (1868), p. 72.

In order to form an idea of the community of species in Miocene times, within the arctic circle, we have the following data:—

	Total Number of Species.	Greenland.	Iceland.	Mackenzie.	Spitzbergen.	Europe.
1. Greenland, .	105	100·0	5·7	7·6	5·7	32·4
2. Iceland, . .	41	14·6	100·0	7·3	12·2	41·5
3. Mackenzie, .	17	47·1	17·7	110·0	23·5	17·7
4. Spitzbergen,	19	31·6	26·3	21·1	100·0	26·3

The last column of this Table shows how close was the connexion between the European Flora in Miocene times and the Flora which then filled certainly more than half the arctic zone.*

* A great circle drawn from Spitzbergen to Behring's Straits divides the arctic zone into two nearly equal parts, the greater of which contains the Polar Miocene plant beds.

Note.

On Rossetti's Law of Cooling, applied to the consideration of the relative effects of Sun-heat, Earth-heat, Star-heat, and Atmospheric Conditions, upon Climates during Geological Time.

Newton's famous Law of Cooling assumed that the Radiation was proportional to the difference between the temperature of the body cooling and the temperature of the "inclosure."

If θ, Θ denote these two temperatures, and t denote the time, Newton's Law is—

$$\frac{d\theta}{dt} = k(\theta - \Theta). \qquad (1)$$

This gives, by integration—

$$t = \frac{1}{k}\log_e(\theta - \Theta) + C, \qquad (2)$$

where k, and C are unknown constants.

This law holds true, as long as the difference of temperatures, $\theta - \Theta$, is not large, but fails entirely when it is great.

Under these circumstances, a new Law of cooling was proposed by Dulong and Petit, which although artificial in its conception, and deviating from the simple idea of the Newtonian Law, nevertheless was found to represent observations better than the Newtonian Law, when the difference of temperatures became greater.

According to this Law—

$$\frac{d\theta}{dt} = A\,(\mu^{\theta} - \mu^{\Theta}), \qquad (3)$$

where $\mu = 1{\cdot}0077$ for all bodies, and A depends on the nature of the cooling body. This relation gives, after some reductions, by integration, the following:

$$t = k \log\left(\frac{\mu^{\theta - \Theta} - 1}{\mu^{\theta - \Theta}}\right) + C, \qquad (4)$$

where k and C are unknown constants.*

Dulong and Petit's Law of cooling fails, as Newton's did, when the difference in temperature between the cooling body and its "inclosure" becomes large.

The most recent advance made in this subject is the important discovery, made by Mr. Rossetti,† that Newton's Law of cooling becomes accurate for great ranges of temperature, provided we make the coefficient, k, a function of the *absolute* temperature of the cooling body, instead of being a constant; and this function turns out to be nearly proportional to the square of the *absolute* temperature.

Newton's Law thus becomes—

$$\frac{d\theta}{dt} = (\theta - \Theta)\,(\alpha T^2 - \beta), \qquad (5)$$

where T is the *absolute* temperature, and β is a very small constant, as compared with α.

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* This equation is the one used in the calculations of page 91, *et seq.*

† "Experiments on radiation have a twofold interest. Accurate measurements of the increase of radiation due to an increase of temperature have of course a great theoretical value, but in addition to this, there is the practical question of a possible measure of temperature by means of the

In order to apply Rossetti's Law of cooling to the case of the earth's surface, I suppose a to be the temperature of the layers of upper atmosphere which controls the radiation of heat from the earth's surface; a being regarded as positive when below zero.

We now have (neglecting β)—

$$\theta - \Theta = \theta + a,$$
$$T = 460 + \theta,$$
$$\beta = 0;$$

and, finally—

$$\frac{d\theta}{dt} = a\,(\theta + a)\,(460 + \theta)^2; \qquad (6)$$

This gives, by integration, after some reductions, and writing A for 460,

$$t = \frac{1}{a\,(A - a)^2}\left\{\log\left(\frac{\theta + a}{\theta + A}\right) - \left(\frac{\theta + a}{\theta + A}\right)\right\} + C. \qquad (7)$$

---

radiation of a body. It is this practical question with special reference to the temperature of the sun which seems chiefly to induce experimenters to study the subject with improved methods. It has led at any rate Mr. Rossetti to furnish a most valuable contribution to the study of radiation.*

"Newton was the first to give a formula connecting the quantity of heat radiated by a body with the temperature of the body; but his formula was not sufficiently accurate, and has been replaced by another first given by Dulong and Petit. But Dulong and Petit's formula also breaks down when the difference of temperature between the radiating body and the "inclosure" is large.

"Mr. Rossetti, trying to improve on Dulong and Petit's formula, deduces from his experiments the following for the radiation of lampblack:—

$$y = a\,T^2\,(T - \theta) - b\,(T - \theta),$$

where y is proportional to the thermal effect of the radiation, a and b are constants, and T and θ are the temperatures of the body and the "inclosure," as measured on the absolute scale. This formula seems certainly to be as

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* Reale Acc. dei Lincei (3) II. 6 Jan. 1878.

The following Table gives the annual Sun-heat and mean annual temperatures of the Northern Hemisphere, neglecting the absorption of the Sun-heat by the atmosphere—

Sun-heat.	Mean temperature.	Latitude, N.
41·9 feet of ice	4°·5 F.	80°
46·3 „	14°·4 „	70°
55·7 „	29°·3 „	60°
66.8 „	43°·4 „	50°
77·3 „	56°·5 „	40°
85·9 „	67°·6 „	30°
92·4 „	77°·6 „	20°
96·5 „	81°·0 „	10°
97·8 „	80°·1 „	0°

far superior to Dulong and Petit's as this latter was to Newton's. The last term generally is but small compared to the first, and Mr. Rossetti believes it to be due to the effect of the surrounding air, although we do not quite see how this can be. The following experiments prove how accurately the formula may be made to represent the facts. The constants a and b were obtained by measuring the radiation of a Leslie's cube filled with water or mercury, and gradually heated up to 300°. A piece of copper foil covered with lampblack was then heated in a flame of alcohol. The temperature of the flame lies between 390° and 400°; and two numbers obtained by means of the above formula were found to lie between these limits. The radiation of a red-hot copper sphere was then determined, and its temperature independently measured by means of a calorimeter. The temperatures obtained by the two methods were 762°·1 and 763°·6 respectively.

"In order to find the temperature of the copper sphere, account was of course taken of the emissive power of copper as compared with lampblack. For this purpose, Mr. Rossetti has invented an ingenious method to determine this emissive power of various metals at the temperature of the Bunsen flame. That a formula obtained by means of experiments made between

From each of these we obtain, by Rossetti's Law (6), an equation, viz.,

$$S = \alpha (\theta + a) (\theta + 460)^2, \qquad (8)$$

where S is the Sun-heat, and θ the mean temperature.

The values of a and α deduced from these equations, taken in pairs, are—

	Latitude.	a.	α.
(1).	80° / 70°	160°·5 F.	$\frac{0{\cdot}2489}{(460)^2}$,
(2).	70° / 60°	100°·2 "	$\frac{0{\cdot}3801}{(460)^2}$,
(3).	60° / 50°	76°·7 "	$\frac{0{\cdot}4644}{(460)^2}$,
(4).	50° / 40°	89°·1 "	$\frac{0{\cdot}4210}{(460)^2}$,
(5).*	40° / 30°	114°·3 "	$\frac{0{\cdot}3590}{(460)^2}$,
	Mean,	**108°·16 F.**	$\frac{0{\cdot}3747}{(460)^2}$
			$= \frac{1}{564{,}718}$.

0° and 300° C. should give such accurate results for a temperature of 760° is already a good proof of the usefulness of the formula, but Mr. Rossetti has pushed his verification even further. A cylinder of oxychloride of magnesium was heated in a flame of coal-gas and oxygen. The temperature was found to be about 960°, and in a flame it was found to be 2,167° and 2,397° in two experiments. Platinum melted easily in the flame, and hence the temperature could not have been far wrong."—*Nature:* "Recent Experiments on Radiation." Vol. xxi. p. 183.

* The Latitudes below 30° give less reliable results, for reasons explained at p. 163, and also because the differences from which a and α are calculated are too small.

This result would indicate for the temperature of the "inclosure" of upper atmosphere that controls the radiation of heat at the earth's surface 108°·16 F.

Frölich,* who has recently made important researches on this subject, with greatly improved and delicate instruments, at St. Petersburgh, has found a similar quantity, called by him *Himmelstemperatur* (Sky-temperature), which varies considerably from month to month and from night to night. Thus he found for the Sky-temperature of the zenith, in 1876:—

20th October,	. . . 123°·70 F.	below zero.
21st "	. . . 119°·29	" "
23rd "	. . . 93°·19	" "
14th August,	. . . 38°·29	" "
15th "	. . . 39°·00	" "
17th "	. . . 49°·09	" "
14th October,	. . . 34°·33	" "

The corresponding results for the Southern Hemisphere are—

Sun-heat.	Mean temperature.	Latitude, S.
55·7 feet of ice,	. . . 35°·3 F.	. . . . . 60°
66·8 "	. . . 47°·8 "	. . . . . 50°
77·3 "	. . . 57°·9 "	. . . . . 40°
85·9 "	. . . 66°·7 "	. . . . . 30°
92·4 "	. . . 74°·7 "	. . . . . 20°
96·5 "	. . . 78°·7 "	. . . . . 10°
97·8 "	. . . 80°·1 "	. . . . . 0°

* *Repertorium für Meteorologie*, Vol. VI., part i., p. 1. (St. Petersburgh, 1876.)

From these data, we obtain, by Rossetti's Law,

	Latitude.		*a.*
(1).	60° } 50°	. . . .	54°·0 F.
(2).	50° } 40°	. . . .	40°·2 „
(3).	40° } 30°	. . . .	60°·3 „
(4).	30° } 20°	. . . .	51°·0 „
(5).	20° } 10°	. . . .	77°·5 „
(6).	10° } 0°	. . . .	90°·3 „
		Mean, . . .	62°·217 F.

From this it follows that the mean "*Sky-temperature*," which controls the radiation of heat from the surface of the earth, is higher in the southern hemisphere than in the northern; so that the southern hemisphere retains more of the heat received from the sun than the northern hemisphere* does.

The *Sky-temperature* of Frölich corresponds with the *Temperature Zenithale* of Pouillet, which is the exact equivalent of the joint action of the atmosphere and of space upon the thermometer.

Both Pouillet and Frölich have attempted to separate the variable effect of the atmosphere from the constant effect of space, and Pouillet finds for the temperature of space (– 142° C.) = – 223·6 F.

* This is due to greater water-surface, and consequently greater amount of aqueous vapour in the air.

Frölich finds for the temperature of space (*Weltraums-temperatur*), by St. Petersburg observations, 17th August and 23rd October, $-131°$ C. and $-127°$ C., the mean of which gives $-202°\cdot2$ F.

The mean result of Pouillet and Frölich is—

Temperature of Space, $= -212°\cdot9$ F.

The term *temperature of space* requires definition, for in one sense it is absurd, because we do not believe in any material particles existing in interstellar or even interplanetary space, capable of receiving and emitting heat. I think that the term *Star-heat* expresses better what we really mean by the temperature of space.

Notwithstanding the high authority of Pouillet, and his ingenious attempts to defend his result, there exists a very general scepticism on the subject.*

If Pouillet had used the term *Star-heat*, he would have been astonished at his own result, viz., that the mean annual heat received by the earth from the sun would melt a sheet of ice-covering equal to 101·7 feet; while in the same time the space-temperature, or Star-heat, would melt an ice-covering equal to 85·3 feet!

Inside any planetary system, the central star or sun must be the chief source of heat, and the effect of the remote stars not appreciable; and, in the space midway between any two stars or suns, the temperature of a

* Pouillet observes, that to us the sun occupies only five-millionths of the celestial vault, whereas the *Space-temperature*, or rather *Star-heat*, acts over the whole vault. To this it may fairly be replied, that as the visible stars appear to us as mere points, the whole of them put together would not form the sun's disc, and that they are indefinitely farther off.

body, if placed there, must fall to the absolute cold, or 460° F. below zero.*

In order to discuss the question of geological climates, let us return to the equation (8), or—

$$H = a(\theta + a)(\theta + A)^2; \dagger \qquad (9)$$

in which H denotes the annual heat received and radiated; a, a coefficient depending upon the radiating surface; a the temperature of the "*heat-inclosure*," including space radiation, and the "convection" and "conduction" of the atmosphere; θ the mean annual temperature of the place of observation; and A = 460° below zero of Fahrenheit, or the temperature of absolute cold.

Between 80° N. Lat. and 70° N. Lat., at present:—

$$a = \frac{0{\cdot}2489}{(460)^2},$$

$$a = 160^\circ{\cdot}5 \text{ F. below zero.}$$

$$A = 460^\circ \text{ F.} \quad ,, \quad ,,$$

In former times, Miocene, Jurassic, and when albumen coagulated, we have H the heat supplied and radiated annually, depending on four quantities, viz.:—

1. Sun-heat.
2. Earth-heat.
3. Thermal properties of the Earth's Atmosphere.
4. Star-heat.

---

* Derived from the well-known relation between the pressure, volume, and temperature of gases; which, in Fahrenheit, units gives the equation—

$$\frac{vp}{460 + \theta} = \frac{v'p'}{460 + \theta'}.$$

† In this equation, θ is reckoned positive above zero, but a, A, positive below zero.

Of these four quantities, the fourth only, or Star-heat, is known; for we may safely assume that, during geological time, the earth and solar system were as far removed as they are now from the influence of any star except that of the sun itself, and that the heat derived from stars was always of no account.

As we cannot separate the effect (in geological times) of the influence of the Sun, Earth, and Atmosphere, I shall consider the following three cases, from which, as I believe, much instruction may be derived:—

(A). The *Sun* as the sole source of heat, the Earth and Atmosphere conditions being as at present.

(B). The *Earth* as the sole source of heat, the Sun and Atmosphere conditions being as at present.

(C). The Thermal properties of the Earth's atmosphere being varied, while the Sun-heat and Earth-heat remain as at present.

(A). *Sun-heat regarded as the sole cause of changes in Geological Climates.*

In this case we have

$$H = \alpha(\theta + a)(\theta + A)^2, \qquad (9)$$

where α, a, A, have the values just given, and at 80° N. Lat.,

θ	=	4°·5 F.	Present time.
θ*	=	44°·3 „	Miocene time.
θ†	=	68°·7 „	Jurassic time.
θ	=	122°·0 „	Coagulation of albumen.

* By interpolation; for at Disco, 70° N. Lat., θ = 55°·6 F., and at Grinnell Land, 81° 44′ N. Lat, θ = 42°·3 F.

† *Vide* p. 82.

Substituting in equation (9), we find—

H	=	41·90	ft. ice melted.		Present.
H	=	61·26	„	„	Miocene.
H	=	75·36	„	„	Jurassic.
H	=	112·56	„	„	Albumen coagulation,

or, as follows :—

Comparative Table of Sun-heats at 80° *N. Lat., at various Geological Periods.*

1. Present time, ...	100·00
2. Miocene time, ...	146.20
3. Jurassic time, ...	179·85
4. Time of coagulation of albumen,	268·60

When we consider that the whole of geological time is as insignificant, in comparison with astronomical time, as the human period is in comparison with geological time; and that in astronomical time the Sun-heat has been reduced to many thousandths of its original value; it will not appear a great effort of the imagination to explain the phenomena of geological climates by the hypothesis of a sun which has cooled down, during geological time, to about one-third of the heat it gave out when life began to be possible, on the earth, at 80° N. Lat.

We may approximate to the relative durations of geological periods, by calculating the times of cooling of the sun, through the differences of the amounts represented in the foregoing Table. Properly speaking, this should be done by a formula similar to (9), in which a would denote the temperature of the "heat-inclosure" of the sun, and a a coefficient depending on the properties of the sun's surface, both of which quantities are completely unknown.

We may, however, obtain an approximate result, by calculating the times of cooling of the sun, on the supposition that it radiates directly into space, neglecting the influence of the solar atmosphere.

This supposition reduces equation (8) to the following:

$$-\frac{d\theta^{*}}{dt} = a(\theta + A)^3. \qquad (10)$$

This gives, by integration,

$$t - t' = \frac{1}{a}\left(\frac{1}{(\theta + A)^2} - \frac{1}{(\theta' + A)^2}\right). \qquad (11)$$

From this equation we find, substituting the proper values (as above given) for θ and θ', the following relative lengths of time:—

1. Present time to Miocene time, ...	41·7
2. Miocene time to Jurassic time, ...	21·1
3. Jurassic time to time of albumen coagulation, .	37·2
	100·0

These numbers are written down to the scale, on which 100 represents the whole possible duration of organic life, from the present time to the time of coagulation of albumen at 80° N. Lat.

* We use the negative sign, because as t increases, θ diminishes.

From the foregoing results the following conclusions may be deduced :—

1. *That the time elapsed from Miocene times to the present time is* 41·7 *per cent. of the whole time of the possible existence of life on the globe at Lat.* 80° *N.* (confirming the conclusions arrived at on page 93).

2. *That the proportion of Palæozoic time to Neozoic time is sensibly the same, whether we measure it by Sun-cooling or by thickness of strata.*

For we find (p. 91),

$$\frac{\text{Palæozoic Rocks}}{\text{Neozoic Rocks}} = \frac{75{,}400}{41{,}050} = 1{\cdot}83;$$

$$\frac{\text{Albumen to Jurassic}}{\text{Jurassic to Miocene}} = \frac{37{\cdot}2}{21{\cdot}1} = 1{\cdot}76.$$

(B). *Earth-heat regarded as the sole cause of changes in Geological Climates.*

It is easy to show that Earth-heat has been always, probably, not a very important factor in geological climates. We may demonstrate this statement as follows. It has been just shown, that if atmospheric conditions were the same as at present, the quantities of heat, at 80° N. Lat., required to keep up the necessary radiation, at various geological times, would be—

	Melted.
Present time, ...	41·90 feet of ice;
Miocene "	61·26 " "
Jurassic "	75·36 " "
Albumen coagulation time,	112·56 " "

and I have already calculated the amounts of increase of Sun-heat sufficient to account for the several climates.

If the Sun-heat had been the same as at present, we have to provide heat from some other source (say Earth-heat) to account for the following excess of radiation above the present radiation at 80° N. Lat.—

	Melted.
Miocene times, ...	19·36 feet of ice ;
Jurassic „	33·46 „ „
Albumen coagulation,. .	70·66 „ „

Let us suppose the earth to be a globe of boiling water, and calculate how long she could keep up the foregoing radiations, before being converted into a globe of ice.

Imagine a cone with its vertex at the centre of the earth, and its base, one square foot, at 80° N. Lat.; the volume of this cone will be, in cubic feet, $\frac{4,000 \times 5,280}{3}$ q.p.

Let e be the excess of heat radiated, at any geological time, above that radiated at present in the same latitude; and let n be the number of years that must elapse before the cone of boiling water is converted into a cone of ice; we now have, since the difference between the boiling and freezing points is 180° F., and since the latent heat of water is 143° F.,

$$143\, e\, n = \frac{4,000 \times 5,280 \times 323}{3};$$

or,

$$n = \frac{4,000 \times 5,280 \times 323}{3 \times 143 \times e}. \qquad (12)$$

From (12) we calculate—

Lengths of time required to convert the cone of boiling water into the cone of ice at 80° N. Lat., at the rates of radiation corresponding to

1.	Miocene time, . . .	821,260 years;
2.	Jurassic „ . . .	475,240 „
3.	Albumen coagulation, .	225,040 „

If we assume, as an approximation to the relative durations of geological times, the numbers given at p. 357, and make use of the mean of the radiations at the beginning and end of each period, we shall find, for the mean radiation at 80° N. Lat., during the entire duration of geological time, the following equation—

Mean radiation of heat at 80° N. Lat. in excess of present radiation

$$= \frac{19{\cdot}36 \times 41{\cdot}7}{200} + \frac{26{\cdot}41 \times 21{\cdot}1}{200} + \frac{52{\cdot}06 \times 37{\cdot}2}{200}$$

$$= 28{\cdot}988 \text{ feet of ice.}$$

From this we calculate the entire duration of geological time, by means of equation (12), to be 548,540 years, or somewhat over half a million of years. But, in reality, the duration of geological time could not have been nearly as great as this if the earth were the sole source of heat, for in the foregoing we have supposed the heat given freely to the surface from the interior, as if the conductivity of the earth were infinite. In reality the heat would be transmitted slowly to the surface, which latter would cool rapidly, making geological time very short, although a large store of heat might remain in the central parts of the earth, not available to mitigate sensibly the rigour of the surface climate.

It is highly probable that the earth cooled down to a condition in which the central heat had but little effect upon climate, long before geological time commenced; so that climates always depended, chiefly, on Sun-heat, modified by atmospheric conditions.

Let us now consider the influence of the latter.

(C). *Atmospheric conditions considered as the sole cause of Geological Climates, the Sun-heat and Earth-heat being the same as at present.*

In the equation (9), or

$$H = \mathbf{a}\,(\theta + a)\,(\theta + A)^2, \qquad (9)$$

$\mathbf{a}$ is a coefficient independent of temperature, depending on the surface conditions of the place of observation.

a, or the control temperature of the "inclosure," depends on the atmosphere and on Star-heat; or on atmospheric conditions only, if Star-heat remained as now through all geological time.

H depends on Sun-heat and Earth-heat only.

At present, at 80° N. Lat., we have

$$H = 41{\cdot}9 \text{ feet of ice.}$$

$$\theta = 4^\circ{\cdot}5 \text{ F.}$$

$$\mathbf{a} = \frac{0{\cdot}2489}{(460)^2}.$$

$$a = 160^\circ{\cdot}5 \text{ F.}$$

In Miocene times

$$H = 41{\cdot}9 \text{ (by hypothesis).}$$

$$\theta = 44^\circ{\cdot}3 \text{ F.}$$

$$a = \frac{0{\cdot}2489}{(460)^2} \ (?)$$

From these data we find, by equation (9), the value of a in Miocene times—

$$a = 95^\circ{\cdot}76 \text{ F.}$$

In like manner, we find the value of a, corresponding to $\theta = 68^\circ{\cdot}7$ F. (Jurassic), and $\theta = 122^\circ{\cdot}0$ F. (albumen coagulation); and finally,

The temperature of the Heat-inclosure, depending on atmospheric conditions necessary to produce the requisite Geological Climates, independent of any increase of Sun-heat or Earth-heat, at 80° *N. Lat.*,

	a
Present time, ...	+ 160°·50 F.
Miocene „	+ 95°·76 „
Jurassic „	+ 58°·73 „
Albumen-Coagulation time,	− 16°·84 „

The positive values are reckoned below zero of Fahrenheit, and the negative values are reckoned above zero.

It is very unlikely that the thermal constants of the earth's atmosphere have ever changed so much as to convert an "inclosure" of 160°·5 below zero into an "inclosure" of 16°·84 above zero, or through 177°·34 F. altogether; nevertheless, it is quite certain that conditions formerly existed in the earth's atmosphere which operated in the direction here indicated, and which may have greatly economised the increase of Sun-heat required, without accounting for the entire change of climate.

Professor Tyndall* has given the following relative absorptive power for heat emanating from a source at 212° F. of various gases at the normal pressure of 30 inches, when a column of the gas, 4 feet in length, was subjected to experiment:—

Absorptive Power of Gases for Non-Luminous Heat.

1. Air,	1	8. Carbonic acid,	90
2. Oxygen,	1	9. Nitrous oxide,	355
3. Nitrogen,	1	10. Sulphuretted hydrogen,	390
4. Hydrogen,	1	11. Marsh gas,	403
5. Chlorine,	39	12. Sulphurous acid,	710
6. Hydrochloric acid,	62	13. Olefiant gas,	970
7. Carbonic oxide,	90	14. Ammonia,	1195

The experiments of Tyndall also establish the fact that aqueous vapour has a powerful absorbent action upon heat of low refrangibility, varying from thirty times to seventy times the effect of pure dry air.

It is quite certain (pp. 78–80) that in Palæozoic times the atmosphere contained a very large proportion of carbonic acid, which has since disappeared, in the way there described; and it is the opinion of many geologists, that as late as Miocene times, there was much more aqueous vapour in the atmosphere than at present. Both of these conditions—one certain and the other probable—would increase the effect of the atmosphere, regarded as a blanket, to keep in the sun-heat received; for we must

* Miller's *Elements of Chemistry*, Part i., pages 338, 339.

observe that while carbonic acid and aqueous vapour would produce but little reduction in the amount of *luminous* Sun-heat received, as compared with pure, dry, air, they would present a formidable obstacle to *non-luminous* heat escaping by radiation from the earth-surface into the cold of star-space.

On the whole, the following appear to me to be the most probable conclusions at which we can arrive as to the causes of former Geological Climates:—

1. We must reject, with contempt, any solution based upon a change of position, either in space or within the earth's body, of the axis of rotation, within the limits of Geological time.

2. We must reject, with respect, any solution based upon the secular cooling of the earth (with a fixed axis of rotation), regarded as the sole and immediate cause of the change of climate.

3. The chief factor in changes of Geological Climate appears to have been the slow secular cooling of the sun, in consequence of which the earth's surface cooled gradually down.*

4. During Palæozoic times the amount of Sun-heat required to keep up the known surface temperatures was *certainly* less than I have calculated from No. 3, because of the large quantity of carbonic acid then forming a part of the atmosphere.

5. During Neozoic times the amount of Sun-heat required to keep up the known surface temperatures was

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* A hot body placed in a cold space would cool down, as the schoolmen would say, *immediately;* but a body deriving its heat from a cooling fire, would cool down *mediately*. The earth has done both, but its chief cause of cooling has been the diminishing heat of the sun.

probably less than I have calculated from No. 3, in consequence of the large quantity of aqueous vapour then existing in the atmosphere as compared with the present time.

6. The so-called Pluvial period and Glacial period were probably the result of atmospheric changes, caused by a temporarily diminished rate of heat-radiation from the sun, producing a precipitation of aqueous vapour, followed by an increased radiation of non-luminous heat into space from the surface of the earth.

APPENDIX.

ADDITIONAL NOTES.

NOTE TO PAGES 82, 83, 84.

On the occurrence of Tropical Fossil Remains in the Liakhov Islands, and in Northern Siberia.

COUNT KEYSERLING* has described four species of *Ceratites* found in the Island of Kotelnoi, and near the Olenek† River, to the westward of the Liakhov Islands. He considers that they belong to the Triassic Period, and are on the same geological horizon as the St. Cassian beds of Spitzbergen.

Higher up the Olenek, at a place called Maak, are found abundant Jurassic fossils, including two Belemnites, five Ammonites, and five other shells; the whole group being Middle Oolitic, and closely resembling the fossil groups found on the Petschora River, south of Nova Zembla.

A similar group of tropical fossils was found near Cape Taimyr.

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* Middendorf, *Siberische Reise* (4 vols.) (1847 to 1860).

† Keyserling also describes a *Nautilus* found on the Olenek, closely resembling the *N. ornatus* of the Liassic Period.

NOTE TO PAGES 85–88.

Letter to the Editor of the "GEOLOGICAL MAGAZINE," *on the Former Climate of the Polar Regions.*

"SIR—In the GEOLOGICAL MAGAZINE for December, 1878, page 552, in a Paper by the Rev. O. Fisher, M.A., on 'The Possibility of Changes in the Latitudes of Places on the Earth's Surface,' the following passage occurs in reference to the question of the possibility of the crust of the earth slipping over a fluid substratum, thereby causing changes of latitude:—'That theory belongs to Dr. Evans; and he has ably defended it against Dr. Haughton's somewhat formidable objections in his recent address to the British Association at Dublin. The supposition alternative to Dr. Evans's, by which Dr. Haughton would account for a former warm climate at the Pole through residual heat in the earth has, I think, been disposed of by anticipation in Sir W. Thomson's Paper on the Secular Cooling.'"

I am not at all prepared to admit either horn of the foregoing dilemma, but shall confine myself at present to the first.

Dr. Evans's address was delivered at the opening of the Geological Section of the Association Meeting, and my Paper, showing the impossibility of accounting for the Tertiary plant-remains in the Arctic Regions by any change in the position at the Pole, was the last Paper read before the Geological Section of that meeting.

I believe that I am correct in stating that neither the President, Dr. Evans, nor any geologist present, gave anything like a satisfactory answer to what the Rev. O. Fisher has called my "somewhat formidable objections."

My contention, in brief, was this, that the Tertiary plant-remains indicating a climate similar to that of Lombardy (so far as heat is concerned) are so situated round the North Pole that no possible change in the position of that Pole (even were such permitted by mechanical considerations) would give them the climatic conditions as to temperature which they require. It was urged at the meeting, as an objection to my view, that the presence of evergreens among the Arctic Tertiary plants was inconsistent with the prolonged absence of light, which they must have sustained if the Pole were in its present position. To this, my reply was the following statement, by Professor W. R. McNab, M.D., of the Royal College of Science:—

"4, Vernon Parade, Clontarf,
"*7th April*, 1878.

"Dear Dr. Haughton,

"I fear I cannot give you a direct answer to your question, and I have not found any Papers on the subject in the 'Botanischer Jahresbericht,' Sachs' 'Lehrbuch der Botanik,' in Sachs' 'Handbuch der Experimental-Physiologie der Pflanzen.' The general facts of the case can, however, be very readily stated.

"Plants containing green chlorophyll grains, when placed in darkness, partial or complete, change colour from the destruction of the chlorophyll. Sachs says (Text-book of Botany, page 669) that in the leaves of rapidly-growing Angiosperms the absorption and disappearance of the chlorophyll takes place in a few days if the temperature be high. He adds, Cactus stems with slow growth, and the shoots of Selaginella, remain green for months in the dark. It is probably true also of Conifers, as I have seen them kept in the dark during the winter months without injury. This I saw in Berlin. Large plants requiring protection from the cold were laid on their sides, and a covering of mats and leaves on a wooden frame placed over them.

"The evergreens in your list are all *Conifers*, and I am of opinion that the absence of light for a considerable period would not injure them.

"It is well known that *cold* alters the colour of the leaves of many Conifers at once, but in your Paper you state the temperature at 48° F., a temperature much too high to influence the colour.

"Your question places an isolated physiological fact in a very important light—at least it appears to do so to me. I give it in Sachs' words (Text-book, page 665): 'If the temperature is sufficiently high, the green colouring substance is found in the *cotyledons* of *Conifers* and in the leaves of Ferns, in *complete darkness* as well as under the influence of light. . . . . Provided, therefore, that the temperature is favourable, the chlorophyll in the cotyledons of Conifers and the leaves of Ferns does not require light in order to assume its green colour, while that in Angiosperms does require it, and in both cases the change does not take place at low temperature.'

"My answer to the objection that has been made to your Paper is this: '*Grant that the evergreens cannot stand prolonged absence of light—that refers to Angiospermous forms. Here all the forms are Coniferous; and Coniferous plants with Ferns have the peculiar property of forming green chlorophyll grains in the dark.*'

"I think a few evergreens do stand prolonged darkness, as I have certainly seen myrtles and rhododendrons placed during the winter in *very dark sheds.*

"As I can only refer to the books in my own library to-day, I shall try to find out some reference to the St. Petersburg observations, and let you know the result in due course.

"I am,

"Very truly yours,

(Signed) "W. R. McNab.

"Rev. Prof. Haughton, F.R.S., etc., etc."

During the discussion on my Paper in the Geological Section, it was observed by Mr. Pengelly that "magnolias" are mentioned by Professor Heer as occurring among the Greenland Tertiary plants. To this my reply was, that although some of the magnolias are evergreens, some of them also have deciduous leaves, and that the occurrence of plants or trees having deciduous leaves should cause us no surprise in the Arctic Regions, provided a suitable temperature were provided for them.*

I cannot give here all the details explained in my Paper, but I claim to have surrounded the North Pole with such a network of Lombardic plants, requiring Lombardic heat, but not Lombardic light, as to render the escape of the Pole from its present position as difficult as that of a "rat from a trap surrounded by terriers."

If the Lombardic light as well as heat were present in these Tertiary times, it would be difficult to explain the *absence* of a

* So far as I can understand, it would be difficult, if not impossible, to distinguish between evergreen magnolias and those with deciduous leaves, in fossil remains.

multitude of evergreen plants which require light to develop chlorophyll grains. Such evergreen plants ought to have migrated from North America and Europe into Greenland as easily and as rapidly as the peculiar groups of evergreens found there in Tertiary times.

In my opinion, the natural selection in the Tertiary Flora of Greenland of such evergreens only as require Lombardic heat, but can dispense with Lombardic light, is a fact which my opponents in the Geological Section not only did not answer, but entirely failed even to see the force of.

SAMUEL HAUGHTON, *Clk.*, M.D.

TRINITY COLLEGE, DUBLIN,
17*th January*, 1879.

NOTE TO PAGE 185.

Rainfall of the Khasi Hills.

"82, PEMBROKE-ROAD,
"*Sept.* 6, 1879.

"MY DEAR DR. HAUGHTON,

"I have at last got the extract which you wished to have about the Cherrapoongee rainfall. It runs as follows:—

"'The highest of any one year, 805 inches, was recorded in 1861. The highest continuous fall recorded is 366 inches, which fell in the month of July, 1861.'

"I myself have known 44 inches to have fallen there in one day, and on the same day 42 inches at Jorrai, which is also situated on the southern edge of the Khasi and Jaintiya Hills, and overlooking the plains of Sylhet.

"With kind regards,
"Believe me,
"Yours very truly,
"C. A. MARTIN."

NOTE TO PAGES 263, 264, 265.

The following interesting letter was published by Mr. Searles V. Wood, Jun., in *Nature* (vol. xxi. p. 347) of 12th February, 1880:—

" *Triassic Footprints.*

"In the *Quarterly Journal* of the Geological Society for August last there is an interesting notice by Mr. Sollas, accompanied by a figure, of a set of footprints from the Triassic beds of South Wales. These footprints Mr. Sollas says he has compared with those of the emu taken in modelling-clay; and so complete was the agreement that, other considerations out of the question, he would not have felt much hesitation in declaring for the avian, and indeed ratitous, character of the animal that produced them; but that because no remains of birds have occurred in the trias of the south-west of England, while those of reptiles have, he refers them to either *Thecodontosaurus* or *Palæosaurus*.

"I wish, therefore, to call attention to the fact that in these footprints there is shown that character of the crossing of one leg over the other, and of turning out the toe, which persons who have kept poultry may have noticed as conspicuous in the walk of the domestic fowl; that is to say, it places the foot, not directly forward, but across the opposite leg, turning the toe well out. Now this is distinctly shown in the relative positions of these Triassic footprints. The first, or lowermost in the figure, is that of the right foot, and the toes point to the right; the next (2) is that of the left foot, and crosses the median line of the animal's path, and the toe of this (for only the middle one remains unobliterated) points well to the left; the third, being that of the right foot, crosses the median line in the same way, its toes pointing well to the right; but the fourth (left), though it thus crosses, has not the toe turned out, because the animal at that point began to bend its course to the right hand.

"This track is thus, I venture to say, one made by the jaunty step of the light-limbed bird, and not by the slouching stride of the heavy-limbed dinosaur, even if this kind of reptile did (as has not yet, notwithstanding its ornithic affinities, been shown) walk erect, and exclusively on two legs; and I am induced to trouble you with these remarks, because just twenty years ago (*Quar. Jour. Geol. Soc.*, vol. xvi. p. 328) I contended that the existing *Ratitæ* and other wingless (or, more accurately, flightless) birds are the direct, and but little altered, descendants of those which inhabited Triassic continents in the southern hemispere, of which one portion, that formed by Australia and New Zealand, has been preserved in complete, and in other portions, such as South Africa and South America, in less complete isolation since that remote period; and it seems to me that the footprints figured by Mr. Sollas furnish very satisfactory evidence of the case.

"SEARLES V. WOOD, Jun.

"MARTLESHAM, NEAR WOODBRIDGE,
"*January*, 30."

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